Universidade Técnica de Lisboa
Instituto Superior de Economia e Gestão
(ISEG - UTL)

Water Tariffs

Methods for an Efficient Cost Recovery and for the Implementation of the Water Framework Directive in Portugal

Henrique Pedro Currais Monteiro

SUPERVISORS

Professor José Manuel de Matos Passos
Professor Maria Catarina Salema Roseta Palma

THESIS COMMITTEE

PRESIDENT:
Dean of the Universidade Técnica de Lisboa

COMMITTEE MEMBERS:
Professor Manuel Victor Moreira Martins, Professor, ISEG - UTL
Professor Rui Jorge Fernandes Ferreira dos Santos, Associate Professor, FCT-UNL
Professor Maria Rita Vieira Martins, Assistant Professor, FE-UC
Professor Maria Catarina Salema Roseta Palma, Assistant Professor, ISCTE-IUL
Professor José Manuel Zorro Mendes, Assistant Professor (Agregado), ISEG-UTL
Professor José Manuel de Matos Passos, Assistant Professor, ISEG-UTL

PhD Dissertation in Economics - Final Version

Lisboa, November 2009

"We never know the worth of water till the well is dry"

Thomas Fuller, Gnomologia, Adagies and Proverbs, Wise Sentences and Witty Sayings, Ancient and Modern, Foreign and British (1732)

"Ce qui embellit le désert, dit le petit prince, c'est qu'il cache un puits quelque part"
(What makes the desert beautiful is that somewhere it hides a well)

Antoine de Saint-Exupery, Le Petit Prince (1943)

Resumo

Este trabalho é um contributo para o estudo da melhor forma de atingir os objectivos de recuperação de custos e eficiência do sector da água em Portugal traçados pela Directiva-Quadro da Água.

Nele se descrevem as tarifas de água e saneamento aplicadas entre 1998 e 2005 e os níveis de recuperação de custos nesse período. As receitas tarifárias angariadas pelas entidades gestoras mostram-se insuficientes para cobrir os custos da sua actividade, especialmente no que diz respeito ao saneamento e a situação tem vindo a piorar nos últimos anos.

A literatura sobre modelização da determinação dos preços da água é revista, salientando alguns resultados importantes como o facto de a eficiência exigir que o preço seja equiparado ao custo marginal, algo que pode não ser possível em simultâneo com restrições de manutenção de orçamentos equilibrados. Não é evidente qual o melhor tipo de tarifário a adoptar, a combinação de uma componente fixa com um preço volumétrico constante ou outro esquema alternativo como os tarifários crescentes por blocos, largamente utilizados em Portugal.

O custo de escassez é incorporado na definição do tarifário óptimo. Demonstra-se que quando a procura e a oferta reagem ambas a factores climatéricos, preços marginais crescentes podem resultar da combinação da escassez de água com a heterogeneidade dos consumidores em situações em que à componente fixa da tarifa apenas é permitido cobrir os custos fixos e é exigido à entidade gestora que mantenha um orçamento equilibrado. A escolha do melhor tarifário depende fundamentalmente do comportamento da elasticidade-preço da procura.

Neste trabalho estimamos a procura residencial de água em Portugal e mostramos que a recomendação sobre o melhor tipo de tarifário depende crucialmente da escolha da forma funcional da procura. Da realização dos testes de especificação adequados, resulta uma escolha inconclusiva entre as formas funcionais semilogaritmíca (lin-log) e loglinear, o que não permite provar a superioridade dos preços crescentes por escalões, mas também não os rejeita.

Estima-se também uma função de custos multi-produto para o sector de abastecimento de água e saneamento português em baixa. Para a entidade gestora de dimensão média existem deseconomias de escala e de gama. Os dois tipos de economias tendem a existir para entidades com maior número de consumidores.

Palavras-Chave: determinação de preços não lineares da água e tarifários crescentes por blocos, escassez de água, recuperação de custos, estimação da procura de água residencial, economias de escala e de gama na função de custos de água, Directiva-Quadro da Água e Lei da Água.

Códigos JEL: C23, C33, C52, D24, D42, L11, L95, Q21, Q25.

Abstract

This work is a contribution to the study of how the Portuguese water industry can meet the goals of cost recovery and water use efficiency set out by the Water Framework Directive.

We describe the Portuguese water and wastewater tariffs implemented from 1998 to 2005 and the cost recovery levels for that period. The tariff revenues collected by the water utilities are insufficient to meet the financial costs of their activities, especially regarding wastewater, and the situation has worsened in recent years.

We review the existing water pricing models, highlighting some important results like the fact that efficiency requires marginal cost pricing, which may not be feasible while respecting a revenue requirement. It is not evident whether the best scheme is a two-part tariff or some other pricing mechanism like increasing block tariffs (IBT), which are abundantly used in Portugal.

We incorporate the scarcity cost associated with insufficient water availability into the optimal tariff design. We show that when both demand and costs respond to climate factors, increasing marginal prices may come about as a combined result of scarcity and customer heterogeneity when the fixed charge is only allowed to cover fixed costs and the utility is required to maintain a balanced budget. Ultimately, the choice of tariff schedule design is dependent on the behavior of the price-elasticity of demand.

We estimate the Portuguese residential water demand and show that the resulting recommended tariff schedule hinges crucially on the choice of functional form. After the proper specification tests, a choice between a semilogarithmic lin-log and a double-log specification is left undecided, which does not prove the superiority of IBT, but also does not enable its dismissal.

We also estimate a multi-output cost function for the Portuguese water industry at the retail level. We find diseconomies of scale and scope for the average water utility. Both types of economies are more likely to exist for utilities with a large customer base.

Keywords: Nonlinear Water Pricing and Increasing Block Tariffs, Water Scarcity, Cost Recovery, Residential Water Demand Estimation, Scale and Scope Economies in the Water Cost Function, Water Framework Directive and Water Law.

JEL codes: C23, C33, C52, D24, D42, L11, L95, Q21, Q25.

Acknowledgments

I would like to thank the people who contributed to make this work possible.

First, I would like to thank my supervisors Professors José Passos and Catarina Roseta Palma for their availability, help and support. During the last few years, I was privileged to have benefited from their knowledge, suggestions, incentive and guidance.

For releasing me from my teaching duties for two and a half years I am in debt to ISCTE-IUL and to my colleagues at the department of Economics. I hope this thesis and my future work may be a good return on investment. I would like to thank Professors José Manuel Henriques and Raul Lopes, the former for providing my first contact with and arousing my interest in water economics as a trainee at the National Water Institute (INAG), the latter for showing me the opportunity to embrace an academic career and introducing me to the world of teaching and research. Special thanks also go to Alexandra Ferreira Lopes, who was a travel companion and a good friend at the Economics PhD programme at ISEG-UTL and as a colleague at ISCTE-IUL and in whose footsteps I often walked.

For diligently providing the data used in this thesis I am obliged to the INSAAR team at the National Water Institute (INAG), the Ministry of Finance and Public Administration, the Regulating Authority on Water and Waste Services (ERSAR, previously called IRAR), the National Weather Institute (Instituto de Meteorologia, I.P.), and the National Statistics Institute (INE). I would like to leave a word of appreciation to the numerous water utility officials who worked to provide the data on the water industry for the INSAAR database and that attentively replied my e-mails and phone calls.

I am grateful for the conditions provided at ISEG-UTL and ISCTE-IUL by the university services and for their prompt technical support, especially the Post-Graduation Office at ISEG and the Office of Computer Services at ISCTE-IUL.

I would like to thank DINÂMIA for providing good organization conditions to develop research projects, for their financial support and for the possibility to disclose intermediate results in their working paper series.

This PhD thesis was financially supported by the National Science Foundation (FCT) through the scholarship SFRH/BD/31190/2006. It was also associated with the research project POCI 2010/EGE/61306/2004–Tarifaqua, supported by the FCT - POCI 2010, co-financed by the European fund ERDF.

Some chapters of this thesis were presented in workshops, seminars and conferences, namely: the Doctoral Workshop on Drinking Water, Economics and Regulation held by the Ecole Polytechnique Fédérale de Lausanne, Switzerland; the Public Policies for Development Conference and the XVIth International Conference of RESER (RESER 2006) held at ISCTE-IUL; the 5^{th} Iberian Congress on Water Planning and Management, in Faro; the 5^{th} and 7^{th} Applied Environmental Economics Conferences (ENVECON 2007; ENVECON 2009) held in London, UK, by the UKNEE – United Kingdom Network of Environmental Economists; the 6^{th} International Conference of the European Water Resources Association (EWRA 2005) in Menton, France; the 8^{th} and 9^{th} Water Congresses of the Portuguese Association for Water Resources (APRH) held at Figueira da Foz and Estoril; the 7^{th} and $8\ ^{th}$ International Conferences of the European Society for Ecological Economics (ESEE 2007; ESEE 2009) in Leipzig, Germany and Ljulbjana, Eslovenia; the 15^{th} and 17^{th} Annual Conferences of the European Association of Environmental and Resource Economists (EAERE 2007; EAERE 2009) in Thessaloniki, Greece and Amsterdam, THe Netherlands; the 2^{nd} National Water Conference and the 9^{th} Conference of the journal Água & Ambiente held at Oeiras and Lisbon; the Environmental and Resource Economics Early Career Researcher Workshop (E-CREW 2007), organized by the Institute for Land, Water and Society, Charles Sturt University in Bathurst, New South Wales, Australia; the 3^{rd} Congress of the Spanish-Portuguese Association of Natural Resources and Environmental Economics (AERNA) in Palma de Mallorca, Spain; the 2^{nd} International Conference on Water Economics, Statistics, and Finance held in Alexandroupolis, Greece by the IWA - International Water Association; the 4^{th} Annual International Symposium on Economic Theory, Policy and Applications, held by the Economics Research Unit of the Athens Institute for Education and Research (ATINER) in Athens, Greece; the 49^{th} European Congress of the RSAI - Regional Science Association International (ERSA 2009), in Lodz, Poland; the 10^{th} Annual Global Conference on Environmental Taxation (GCET 2009), in Lisbon, Portugal; the seminars organized by IRAR (now ERSAR) and DINÂMIA and the doctoral seminar at ISEG-UTL. I am very grateful to the organizers, referees and participants for the opportunity to have this work discussed and for all their comments, which contributed to the improvements in this work. Special thanks also to Rita Martins and Patrícia Luís-Manso from whose experience, previous work on the Portuguese water industry and exchange of ideas I was able to benefit. The usual disclaimer applies.

I would like to thank my sister for enduring my distance during this period and my parents, whose sacrifices for the education of their children are an example to us all and to whom I will always be in debt for the opportunities and prospects I have been able to enjoy. Finally I am grateful to my wife Carla Soares on whose company, love and support rests the success of this endeavour.

List of Acronyms

2SLS: Two-Stage Least Squares

3SLS: Three-Stage Least Squares

AdP: Águas de Portugal [Portuguese State's holding company for the Water and Waste Industries]

AERNA: Associação Hispano-Portuguesa de Economistas do Ambiente e dos Recursos Naturais [Spanish-Portuguese Association of Environmental and Resource Economists]

AMECO: Annual Macro-economic Database of the European Commission's Directorate General for Economic and Financial Affairs (DG ECFIN)

AP: Average Price

APA: Agência Portuguesa do Ambiente [Portuguese Environmental Agency]

APDA: Associação Portuguesa de Distribuição e Drenagem de Águas [Portuguese Association of Water Suppliers and Wastewater Drainage]

APESB: Associação Portuguesa de Engenharia Sanitária e Ambiental [Portuguese Association of Sanitary and Environmental Engineering]

APRH: Associação Portuguesa de Recursos Hídricos [Portuguese Association of Water Resources]

AR: Assembleia da República [Portuguese Parliament] / Autoregressive

ARIMA: Autoregressive Integrated Moving Average

ATINER: Athens Institute for Education and Research

AWWA: American Water Works Association

BFGS: Broyden-Fletcher-Goldfarb-Shanno method

BMS: Amemiya, MaCurdy and Breusch

CGE: Computable General Equilibrium

DBT: Decreasing Block Tariffs

DCC: Discrete-Continuous Choice Model

DG ECFIN: European Commission's Directorate General for Economic and Financial Affairs

EAERE: European Association of Environmental and Resource Economists

EAGCP: Economic Advisory Group on Competition Policy

EC: European Commission

E-CREW: Early-Career Researcher Workshop on Environmental and Resource Economics

ECU: European Currency Unit

EEA: European Environmental Agency

EPA: United States Environment Protection Agency

EPAL: Empresa Portuguesa de Águas Livres [Lisbon's Water Company]

ERDF: European Regional Development Fund

ERSA: European Regional Science Association

ERSAR: Entidade Reguladora dos Serviços de Água e Resíduos [Regulating Authority on Water and Waste Services]

ESEE: European Society for Ecological Economics

EU: European Union

EWRA: European Water Resources Association

FAO: Food and Agriculture Organization

FE: Fixed Effects

FGLS: Feasible Generalised Least Squares

GCET: Global Conference on Environmental Taxation

GDP: Gross Domestic Product

GLS: Generalised Least Squares

GMM: Generalised Method of Moments

IBT: Increasing Block Tariffs

ICWE: International Conference on Water and the Environment

IA: Instituto do Ambiente [Institute for the Environment]

IID: Independent and Identically Distributed Random Variable

INAG: Instituto da Água [National Water Institute]

INE: Instituto Nacional de Estatística [National Statistics Institute]

INSAAR: Inventário Nacional de Sistemas de Abastecimento de Água e Águas Residuais [National Inventory of Water Supply and Wastewater Systems]

IPCC: Intergovernmental Panel on Climate Change

IPSS: Instituições Particulares de Solidariedade Social [Private Social Solidarity Institutions]

IRAR: Instituto Regulador de Águas e Resíduos [Regulating Authority on Water and Waste]

ISCTE-IUL: Instituto Universitário de Lisboa [Lisbon University Institute]

ISEG-UTL: Instituto Superior de Economia e Gestão - Universidade Técnica de Lisboa [Higher Institute for Economics and Management - Technical University of Lisbon]

IV: Instrumental Variables

IWA: International Water Association

LNEC: Laboratório Nacional de Engenharia Civil [National Laboratory of Civil Engineering]

LSDV: Least Squares Dummy Variables

LTF: Linear Transfer Function

MA: Ministério do Ambiente [Ministry of the Environment]

MAOT: Ministério do Ambiente e do Ordenamento do Território [Ministry of the Environment and Spatial Planning]

MAOTDR: Ministério do Ambiente, do Ordenamento do Território e do Desenvolvimento Regional [Ministry of the Environment, Spatial Planning and Regional Development]

ML: Maximum Likelihood

MP: Marginal Price

MWWS: Municipal Water and Wastewater Survey

NLS: Nonlinear Least Squares

NLSUR: Nonlinear Seemingly Unrelated Regressions

NUTS: Nomenclatura das Unidades Territoriais para fins Estatísticos [Nomenclature of Territorial Units for Statistics]

OECD: Organisation for Economic Co-operation and Development

OFWAT: Office of Water Services (Water Services Regulating Authority in England and Wales)

OLS: Ordinary Least Squares

PCSE: Panel-Corrected Standard Errors

PEAASAR: Plano Estratégico de Abastecimento de Água e Saneamento de Águas Residuais [Strategic Plan for Water Supply and Wastewater Sewage]

PEAASAR I: Plano Estratégico de Abastecimento de Água e Saneamento de Águas Residuais 2000-2006 [Strategic Plan for Water Supply and Wastewater Sewage 2000-2006]

PEAASAR II: Plano Estratégico de Abastecimento de Água e Saneamento de Águas Residuais 2007-2013 [Strategic Plan for Water Supply and Wastewater Sewage 2007-2013]

RASARP: Relatório Anual do Sector de Águas e Resíduos em Portugal [Annual Report on the Water and Waste Industry in Portugal]

RE: Random Effects

RESER: European Association for Research in the Service Industry

RSAI: Regional Science Association International
SC: Special Contracts
SUR: Seemingly Unrelated Regressions
UK: United Kingdom
UKNEE: United Kingdom Network of Environmental and Resource Economists
UN: United Nations
UNDP: United Nations Development Programme
UNEP: United Nations Environmental Program
USA: United States of America
WFD: Water Framework Directive
WS: Water Supply
WW: Wastewater
WWAP: World Water Assessment Programme
WWDT: Wastewater Drainage and Treatment

Contents

Preface **1**

1 Portuguese water supply and wastewater tariffs' evolution 1998-2005 **5**
1.1 Introduction 5
1.2 Criteria for the analysis of a tariff scheme 13
1.3 Portuguese water tariffs 17
1.3.1 Water supply tariffs 18
1.3.2 Wastewater drainage and treatment tariffs 39
1.4 Conclusion 47

2 Evolution of Cost Recovery Levels in the Portuguese Water Supply and Wastewater Industry 1998-2005 **49**
2.1 Introduction 49
2.2 Cost recovery in Portuguese Law 51
2.3 Methodology 54
2.4 Brief description of water and wastewater utilities 56
2.4.1 Nature of the service 56
2.4.2 Type of utility 57
2.4.3 Geographical distribution 61
2.5 Costs 63
2.5.1 Total costs 63
2.5.2 Operation costs 65
2.5.3 Investment costs 66
2.5.4 Costs per utility and unit costs 68
2.5.5 Rates of change in costs 77
2.6 Revenues 83
2.6.1 Total revenues 83
2.6.2 Tariff revenues 85
2.6.3 Non-tariff revenues 86
2.6.4 Revenues per utility and unit revenues 88
2.6.5 Rates of change in revenues 94

2.7 Cost recovery levels . . . 98
2.8 Conclusion . . . 105

3 Water Pricing Models: a Survey **107**
3.1 Introduction . . . 107
3.2 Existing water pricing schemes . . . 108
3.3 Water pricing models . . . 109
3.3.1 Average vs. Marginal cost pricing . . . 111
3.3.2 Seasonal or temporal variations . . . 113
3.3.3 Capacity constraints or expansion decisions . . . 116
3.3.4 Scarcity . . . 118
3.3.5 Revenue requirements . . . 119
3.3.6 Metering . . . 122
3.3.7 Efficiency of block tariffs . . . 123
3.4 Conclusion . . . 124

4 Pricing for Scarcity **127**
4.1 Introduction . . . 127
4.2 Existing water tariffs . . . 129
4.3 Scarcity in a simple model . . . 131
4.4 Scarcity with a distribution of consumer types . . . 134
4.5 Scarcity in demand, cost and availability . . . 136
4.5.1 Impact of scarcity on the shape of the price schedule . . . 137
4.5.2 Impact of scarcity on water consumption . . . 139
4.6 Dynamic analysis of scarcity . . . 141
4.7 Conclusion . . . 143

5 Residential Water Demand in Portugal: checking for efficiency-based justifications for increasing block tariffs **146**
5.1 Introduction . . . 146
5.2 An efficiency justification for increasing block tariffs . . . 150
5.3 The importance of the choice of functional form . . . 152
5.3.1 Linear specification . . . 153
5.3.2 Double-log specification . . . 154
5.3.3 Semilogarithmic specification (log-lin) . . . 154
5.3.4 Semilogarithmic specification (lin-log) . . . 155
5.3.5 Stone-Geary demand function and reciprocal functions in general . . 155
5.3.6 Summary of implications of the choice of functional form on elasticities of demand . . . 156
5.4 Literature review . . . 158
5.5 The model and the data . . . 161
5.6 Methodology, estimation and results for a linear functional form . . . 166

5.7 Functional form specification tests 184
5.8 Conclusion 189

6 Estimation of Cost Functions for the Portuguese Water and Wastewater Industry 191
6.1 Introduction 191
6.2 Literature review 193
6.3 Models and methodology 197
6.4 The data 200
6.5 Empirical results - Economies of scale for water supply 207
6.6 Empirical results - Economies of scale for wastewater drainage and treatment 218
6.7 Economies of scale and scope with a multi-output cost function for water supply and wastewater drainage and treatment 224
6.8 Conclusion 230

A Derivation of equation 4.16 232

B Formulation and solution to the dynamic water pricing and investment model with a financial constraint 234

C Residential water demand estimation studies 236

D Water cost function estimation studies 310

List of Tables

1.1 Comparison of two different calculation procedures for a block tariff 26
1.2 Frequency and motive for the use of special contracts regarding the fixed part of the retail WS tariff (2002) 31
1.3 Frequency and motive for the use of special contracts regarding the variable part of the retail WS tariff (2002) 32
1.4 Average tariff for a regular monthly consumption of 10 m3 by residential customers disaggregated by type of utility (2002-2005) 38
1.5 Range of variation of the tariff for a regular monthly consumption of 10 m3 by residential customers disaggregated by type of utility (2002-2005) 38
1.6 Base variables for the fixed part of the wastewater drainage and treatment tariff (1998-2005) 42
1.7 Frequency and motive for the use of special contracts regarding the fixed part of the retail WWDT tariff (2002) 45
1.8 Frequency and motive for the use of special contracts regarding the variable part of the retail WWDT tariff 46

2.1 WS and WWDT systems' costs (2005) 65
2.2 Unit cost by type of utility in retail WS and WWDT (2005) 77
2.3 Average annual rate of change in costs in WS and WWDT (1998-2005) . . 79
2.4 Average annual rate of change in per customer unit costs in WS and WWDT (1998-2005) 81
2.5 Average annual rate of change in per m3 unit costs in WS and WWDT (1998-2005) 82
2.6 Unit revenues by type of utility in retail WS and WWDT (2005) 94
2.7 Average annual rate of change in revenues in WS and WWDT (1998-2005) 95
2.8 Average annual rate of change in per customer unit revenues in WS and WWDT (1998-2005) 96
2.9 Average annual rate of change in per m3 unit revenues in WS and WWDT (1998-2005) 97
2.10 Cost recovery levels for mainland Portugal by type of system (2002-2005) . 99

2.11 Percentage of water/wastewater utilities and corresponding volumes supplied/drained with cost recovery ratios above and below unity in WS and WWDT (2002-2005) . . . 100
2.12 Cost recovery levels in mainland Portugal in WS and WWDT (2002-2006) . 101
2.13 Cost recovery ratios by type of utility in retail WS and WWDT (2005) . . . 105

3.1 Questions addressed by the water pricing models . . . 110

5.1 Price-elasticities of demand for several functional forms . . . 157
5.2 Income-elasticities of demand for several functional forms . . . 158
5.3 Definition of variables . . . 162
5.4 Summary statistics . . . 162
5.5 Definition of the variables used to instrument mptotal and diftotal . . . 167
5.6 Summary statistics of the variables used to instrument mptotal and diftotal 168
5.7 GLS regressions with AR(1) disturbances for several functional forms . . . 185
5.8 Summary of elasticity results for several functional forms . . . 185
5.9 Specification tests results and resulting preferred functional form . . . 187

6.1 Definition of the variables used in the water supply cost function . . . 201
6.2 Summary statistics of the variables used in the water supply cost function - all water utilities . . . 202
6.3 Definition of the variables used for the wastewater drainage and treatment cost function . . . 204
6.4 Summary statistics of the variables used in the wastewater drainage and treatment cost function - all wastewater utilities . . . 204
6.5 Definition of the variables used for the multi-output water and wastewater cost function . . . 205
6.6 Summary statistics of the variables used in the multi-output water and wastewater cost function - all water and wastewater utilities . . . 206
6.7 Translog parameter estimates for the water supply cost function . . . 208
6.8 Summary statistics of the variables used in the water supply cost function - utilities with complete information . . . 212
6.9 Correlation matrix for water supply outputs and customers . . . 215
6.10 Translog parameter estimates for the wastewater drainage and treatment cost function . . . 219
6.11 Summary statistics of the variables used in the wastewater drainage and treatment cost function - utilities with complete information . . . 220
6.12 Translog parameter estimates for the multi-output water supply and wastewater drainage and treatment cost function . . . 225
6.13 Summary statistics of the variables used in the multi-output water supply and wastewater drainage and treatment cost function - utilities with complete information . . . 226

6.14 Scope economies for different utility sizes 229

List of Figures

1.1 Freshwater availability, m^3 per person and per year (2007) 6
1.2 Water stress indicator in major river basins (taking into account environmental water requirements) 7
1.3 Change in water availability compared with average 1961-1990 (%) 2050 based on IPCC scenarios A1 8
1.4 Changes in annual precipitation for the IPCC A2 scenario (2071–2100 compared with 1961–1990) for four different climate models 9
1.5 Distribution of reported WS customers/meters by customer type (2005) . . 19
1.6 Distribution of reported retail WS volumes by customer type (2005) 19
1.7 Types of tariffs in WS by customer type (2005) 20
1.8 Fixed part of the residential WS tariff (2005) (average weighted by the number of residential meters) 21
1.9 Percentage difference in the fixed part of the WS tariff relative to the residential customers by pipe diameter (average weighted by the total number of meters) (2005) 22
1.10 Average annual rate of change of the fixed part of the WS tariff by type of customer and pipe diameter (average weighted by the total number of meters) (1998-2005) 23
1.11 Types of volumetric components of WS tariffs by customer type (2005) . . . 24
1.12 Number of blocks in the variable part of the WS tariff by customer type (2005) 25
1.13 Marginal and average tariff for residential customers weighted by the retail volume of water supplied (2005) 27
1.14 Marginal and average tariff for a typical water utility (5 blocks and the volume charged within the block - the corresponding block price is charged to each m^3) (residential customers 2005) 28
1.15 Marginal and average tariff for a typical water utility which charges all the volume at the price of the highest block reached (residential customers 2005) 28
1.16 Marginal and average tariffs for a tariff schedule with the implementation of the formula V*(X+ (V-Li)*Y) (residential customers 2005) 30
1.17 Percentage difference in the variable part of the WS tariff relative to the residential customers (average weighted by the total volume supplied) (2005) 34

1.18 Average tariff per m^3 in WS by customer type (2005) 35
1.19 Average annual rate of change of the variable part of the WS tariff by type of customer (average weighted by the volume of retail water supplied) (1998-2005) 36
1.20 Average tariff for a monthly consumption of $10m^3$ by a residential customer disaggregated at the NUTS III sub regional level (1998-2005) 37
1.21 Distribution of reported WWDT customers by customer type (2005) 39
1.22 Distribution of reported wastewater volume drained by customer type (2005) 40
1.23 Types of WWDT tariffs by customer type (2005) 41
1.24 Base variables for the fixed part of the wastewater drainage and treatment tariff (2005) 43

2.1 Classification of utilities by the nature of the service provided (2005) 56
2.2 Type of water utility/management (2002-05) 57
2.3 Distribution of retail WS utilities by type (2005) 59
2.4 Distribution of bulk WS utilities by type (2005) 59
2.5 Distribution of retail WWDT utilities by type (2005) 60
2.6 Distribution of bulk WWDT utilities by type (2005) 60
2.7 Geographical distribution of the main retail WS utilities in each municipal county (2002 and 2005) 62
2.8 Geographical distribution of the main retail WWDT utilities in each municipal county (2002 and 2005) 62
2.9 Total costs declared for WS and WWDT systems (2005) 64
2.10 Distribution of operation costs reported in WS and WWDT (2005) 66
2.11 Evolution of investment costs in WS (1987-2005) 67
2.12 Evolution of investment costs in WWDT (1987-2005) 68
2.13 Average cost per utility in WS and WWDT systems (2005) 69
2.14 Annual unit cost per customer in retail WS and WWDT systems (2005) . . 70
2.15 Average unit cost per m^3 in WS and WWDT systems (2005) 71
2.16 Average cost per utility in retail WS and WWDT by NUTS III (2005) . . . 72
2.17 Average unit cost per customer in retail WS and WWDT by NUTS III (2005) 73
2.18 Average unit cost per m^3 in retail WS and WWDT by NUTS III (2005) . . 74
2.19 Population density and altitude variation by NUTS III (2005) 75
2.20 Water quality indicators: sampling frequency failures and mandatory quality parameters failures by municipality (2005) 76
2.21 Revenues in WS and WWDT systems (2005) 84
2.22 Distribution of retail WS and WWDT tariff revenues (2005) 86
2.23 Disaggregation of non-tariff revenues in WS (1998-2005) 87
2.24 Disaggregation of non-tariff revenues in WWDT (1998-2005) 88
2.25 Average revenue per utility in WS and WWDT systems (2005) 89
2.26 Annual unit revenues per customer in retail WS and WWDT systems (2005) 89

2.27 Average unit revenue per m^3 in WS and WWDT systems (2005) 90
2.28 Average revenue per utility in retail WS and WWDT by NUTS III (2005) . 91
2.29 Average unit revenue per customer in retail WS and WWDT by NUTS III (2005) 92
2.30 Purchasing power index and household disposable income per capita (2005) 92
2.31 Average unit revenue per m^3 in retail WS and WWDT by NUTS III (2005) 93
2.32 Cost recovery ratios in retail WS by NUTS III (2002-2005) 103
2.33 Cost recovery ratios in retail WWDT by NUTS III (2002-2005) 103

5.1 Random effects regression for *mptotal* 168
5.2 Random effects regression for *diftotal* 169
5.3 Davidson and MacKinnon test of exogeneity for *mptotal* 170
5.4 Davidson and MacKinnon test of exogeneity for *diftotal* 171
5.5 Tests of instrument relevance and validity for *mptotal* 173
5.6 Tests of instrument relevance and validity for *diftotal* 174
5.7 Bresch Pagan Lagrangian multiplier test for random effects 175
5.8 Heteroskedasticity and autocorrelation tests 176
5.9 Estimation results 178
5.10 Random effects regression for *aptotal* 180
5.11 Davidson and MacKinnon test of exogeneity for *aptotal* 181
5.12 Tests of instrument relevance and validity for *aptotal* 182
5.13 Estimation result of the auxiliary model for the price perception test 183

6.1 Economies of output density in water supply 214
6.2 Economies of scale in water supply 214
6.3 Economies of output density in water supply for different utility sizes 216
6.4 Economies of scale in water supply for different utility sizes 216
6.5 Economies of output density in wastewater drainage and treatment 222
6.6 Economies of scale in wastewater drainage and treatment 222
6.7 Economies of output density in wastewater drainage and treatment for different utility sizes 223
6.8 Economies of scale in wastewater drainage and treatment for different utility sizes 223
6.9 Economies of output density for the multi-output water supply wastewater drainage and treatment cost function for different utility sizes 227
6.10 Economies of scale for the multi-output water supply and wastewater drainage and treatment cost function for different utility sizes 227

Preface

In 23 October 2000 the Directive 2000/60/EC of the European Parliament and Council was approved. It is known as the Water Framework Directive (WFD) and it establishes a framework for an European policy on water resources. The directive was transposed to the Portuguese Law with the publication of the Law n. 58/2005 of 29 December, known as the Water Law.

These legal documents contain innovative features regarding their economic aspects, for example by integrating the perception that water is a scarce resource. The following requirements are imposed on the Member-States[1]:

- to perform an economic analysis of the several water uses (art. 5, WFD; art. 29, n.1, g), Water Law);

- to integrate in the River Basin Management Plans until 2010 a programme of measures that (art. 9, n. 1, WFD; art. 30, 77 and 83 Water Law):

- takes into account the cost recovery of water services (including environmental and resource costs);

- ensures that water pricing policies provide adequate incentives for users to use water resources efficiently and thereby contribute to the Directive's environmental objectives in terms of quality of the water bodies;

- ensures an adequate contribution of the different water users (industry, households, agriculture) to the recovery of the costs of water services.

This work is a contribution to the study of how cost recovery and water use efficiency can be achieved in Portugal, thereby complying with the requirements of the WFD and the new Water Law. It focuses on the role that water tariffs may have in this regard combining the analysis of water demand and supply as required by proper economic analysis (Roseta-Palma (2002)). It is not our intention to describe the broader framework of the regulation of public utilities nor to examine the context of economic regulation of the water industry. Such a task has already been undertaken and can be found in the works of Cardadeiro (2005) and Martins (2007) for the Portuguese case and Luis-Manso (2007) and Finger,

[1] See Roseta-Palma (2002) and WATECO (2003) for a more detailed description of the impacts of the WFD on the Portuguese economic water policy.

Allouche and Luis-Manso (2007) in a more European perspective. We deliberately choose to focus on the cost recovery and efficient/incentive pricing issues. In this preface we describe the structure of the thesis and the main findings.

We start by describing the Portuguese water and wastewater tariffs implemented in the period 1998-2005, based on the data provided by the National Water Institute (INAG) in the National Inventory of Water Supply and Wastewater Systems (INSAAR)[2]. The increasing popularity of increasing block tariffs (IBT) for water is reflected in Portugal by a virtually universal implementation for residential use. We compare the current water pricing policies with the main criteria used for evaluating a tariff schedule. From this comparison, we conclude that, halfway between the publication of the WFD and the 2010 deadline for the implementation of efficient pricing policies, there was still a long way to go.

In Chapter 2, we describe the situation in Portugal in 2005 regarding cost recovery in the water supply (WS) and wastewater drainage and treatment (WWDT) industry and its evolution since 1998. We also present a brief historical overview of the presence of the cost recovery principle in the Portuguese law regarding the industry. The main conclusions that stand out are: the introduction of the cost recovery principle is prior to the WFD and the more recent Water Law, although it lacked practical implementation; the level of revenues collected by the WS and WWDT utilities is insufficient to meet the financial costs of their activities; the situation is worse for wastewater than for WS systems, revealing evidence of cross-subsidization within the utilities which manage both systems; the situation has worsened in recent years; cost recovery levels are lower in the less densely populated and poorer inland regions; finally, we find no evidence associating cost recovery levels and the type of utility.

We review the existing water pricing models in Chapter 3, highlighting some important results. Efficiency requires marginal cost pricing, a useful tool to restrain demand in scarcity conditions and to signal the value that consumers attribute to further capacity

[2] We collected additional information on water tariffs, volumes supplied/collected and number of customers through direct contact with all water and wastewater utilities in mainland Portugal which add to the INSAAR data, mainly by the filling of missing data in the original database.

expansions as the water supply system approaches its capacity limit. Intra-annual price changes or customer differentiation to reflect differences in marginal costs can enhance efficiency. However, pure marginal cost pricing may not be feasible while respecting a revenue requirement. The most common ways of combining efficiency and revenue requirements are through the use of two-part tariffs, adjusting the fixed charge to meet the revenue requirement, or through second-best pricing like Ramsey pricing. It is not evident whether the best scheme is a two-part tariff or some other pricing mechanism. The role of block rate pricing, increasingly more frequent in actual pricing practices, has not yet been fully investigated.

In many areas where water is not abundant, water pricing schedules contain significant nonlinearities. Existing pricing literature establishes that efficient schedules will depend on demand and supply characteristics. However, most empirical studies show that actual pricing schemes have little to do with theoretical efficiency results. In particular, there are very few models recommending increasing blocks, whereas we present evidence that this type of tariff structure is abundantly used, namely in Portugal. Water managers often defend increasing blocks, both as a means to benefit smaller users, to signal scarcity and to achieve revenue neutrality. Naturally, in the presence of water scarcity the true cost of water increases due to the emergence of a scarcity cost. In Chapter 4, we incorporate the scarcity cost associated with insufficient water availability into the optimal tariff design in several different models. We show that when both demand and costs respond to climate factors, increasing marginal prices may come about as a combined result of scarcity and customer heterogeneity when the fixed charge is only allowed to cover fixed costs and the utility is required to maintain a balanced budget. We also investigate the effect that rising water scarcity in the long run can have on the steady-state amount of capital invested in water storage and supply infrastructures and obtain some results that are consistent with the static models.

Because, in the conditions described above, the choice of tariff schedule design is dependent on the price-elasticity of demand and the way it varies with consumption levels, in Chapter 5 we estimate the Portuguese residential water demand and show that the resulting recommended tariff schedule hinges crucially on the choice of functional form. After the proper specification tests, a choice between a semilogarithmic lin-log and a double-log specification is left undecided, which does not prove the superiority of IBT, but also does not enable its dismissal. Besides the usual determinants found in the prolific residential water demand estimation literature we find that the proportion of seasonally inhabited dwellings and a reduced water quality on delivery can have a significant negative influence on the amount of water households consume.

To improve the situation in the Portuguese water industry regarding cost recovery either tariff revenues would have to increase or cost savings would have to be achieved. We estimate the cost function of the Portuguese water industry at the retail level in Chapter 6, testing for the existence of economies of scale and scope, taking into consideration the amount of water losses and the combination of the water supply and wastewater drainage and treatment activities. Our results differ from previous research for the Portuguese water industry in that for the sample average we find diseconomies of scale for water supply and for utilities combining the water supply and wastewater drainage and treatment activities, while for wastewater we do find evidence of economies of scale. The size of the utility, as measured by its customer base, and the control of water losses are found to favour the existence of economies of scale. Diseconomies of scope are found for the combined activities of water supply and wastewater drainage and treatment, but the situation improves with the utility size and for utilities larger than three times the sample average economies of scope do exist.

Summing up, to the extent that we find no possible cost savings for the average retail water and wastewater utility can be made from merging neighbouring systems, achieving cost recovery may have to be achieved through the increase of the water price. Because two-part tariffs with lump-sum fixed charges are not permitted in Portugal, IBT may be a second-best alternative to achieve both the goals of water use efficiency and financial sustainability in a context of increasing water scarcity, although their use must be properly assessed in a rational manner.

Chapter 1

Portuguese water supply and wastewater tariffs' evolution 1998-2005

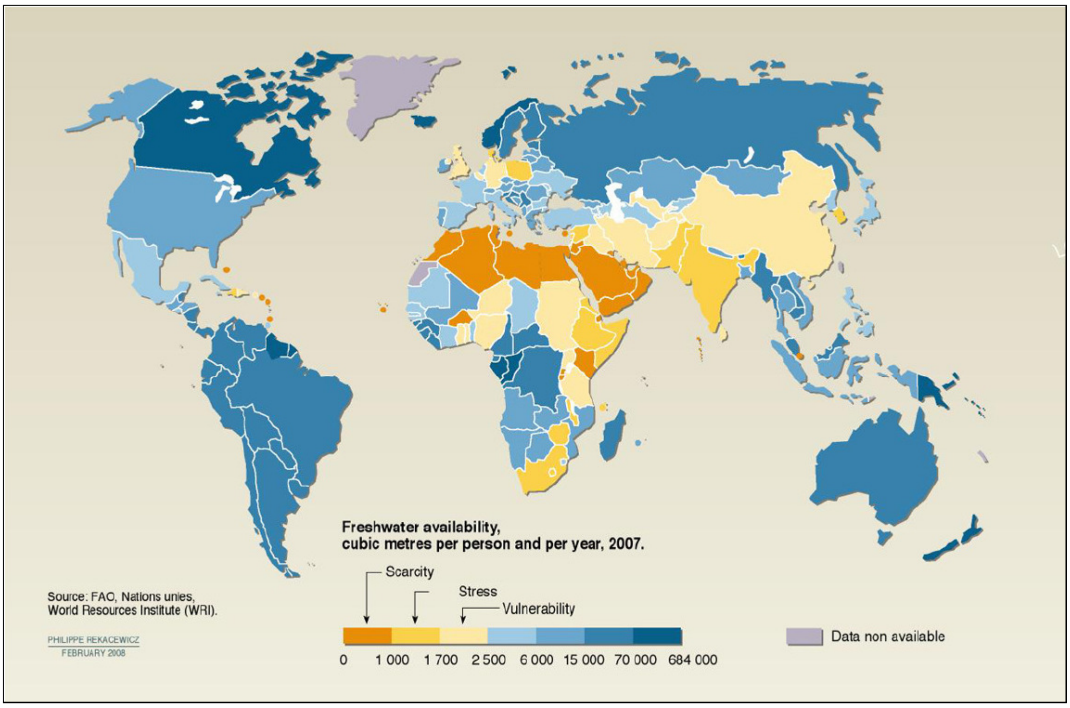
1.1 Introduction

The European Union has a reasonable level of water availability, although it is unevenly spread across its Member-States and Portugal is an average country regarding the water exploitation index[1]. Figure 1.1 [2] shows that Portugal is not considered a vulnerable or stressed region regarding water resources use.

[1] Water exploitation index = Total water abstraction per year as a % of long-term freshwater resources (EEA (2007*b*), p. 92) (see also EC (2007*c*), p. 26).

[2] The source of Figure 1.1 is UNEP (2008). The original source is FAO – Food and Agriculture Organization of the United Nations and the World Resources Institute.

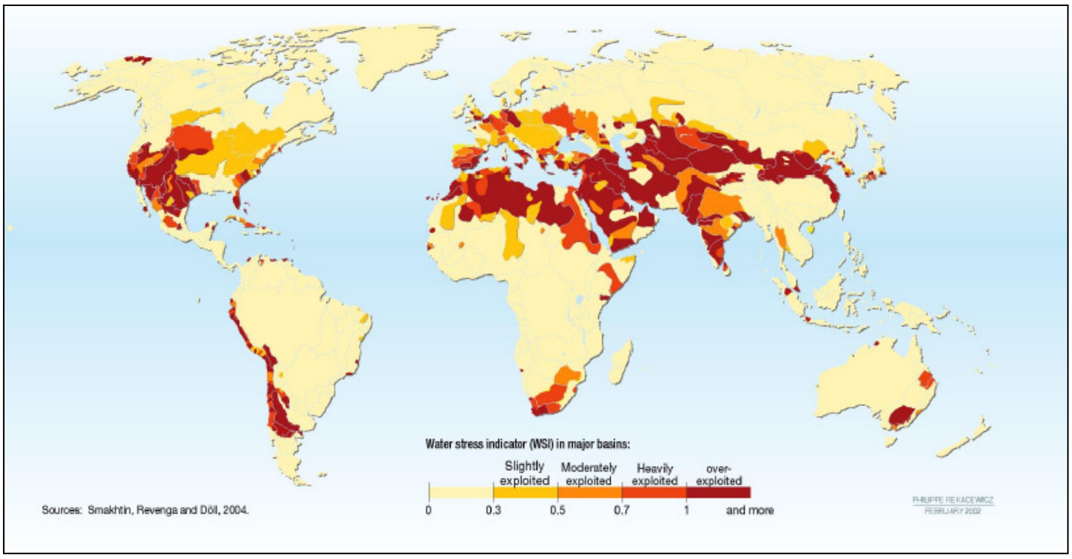
Figure 1.1: Freshwater availability, m^3 per person and per year (2007)



However, Portugal is one of the five European Union countries where the water exploitation index has increased from 1990 to 2004 (EEA (2007*b*), p. 92), resulting in increased pressure on water resources. Figure 1.2 [3] shows that the international river basins from where Portugal withdraws most of its renewable water are already moderately or highly exploited.

[3] The source of Figure 1.2 is UNEP (2008). The original source of is Smakhtin, Revenga and Döll (2004).

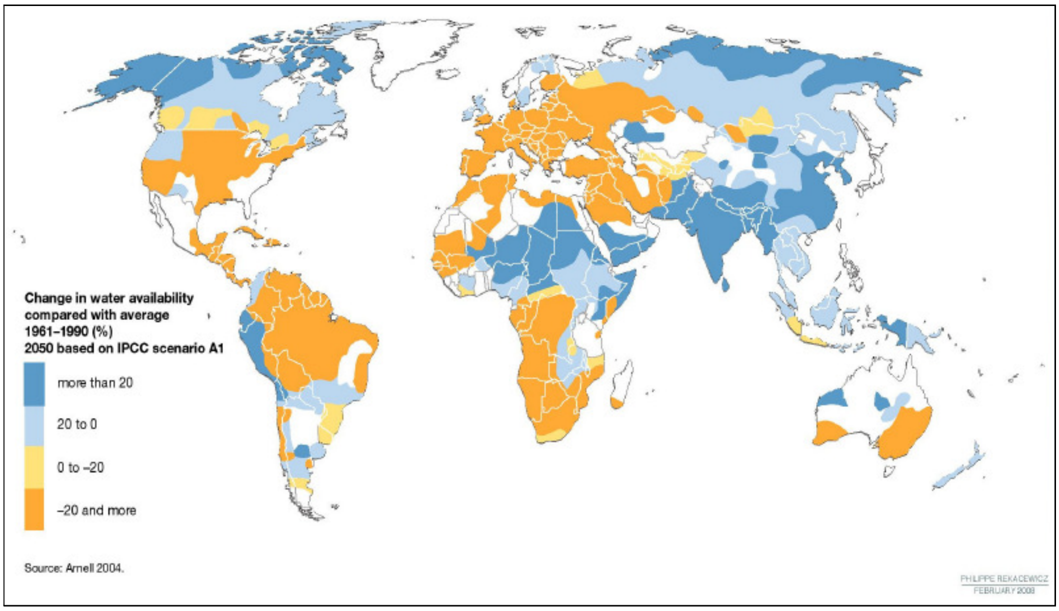
Figure 1.2: Water stress indicator in major river basins (taking into account environmental water requirements)



Moreover, in Portugal there is a significant variability in the availability of water resources, with recurrent drought/scarcity situations which are forecasted to worsen in the coming years due to climate change. Figure 1.3 [4] shows that Portugal is included in the regions where climate change will impose a greater reduction in water availability in the coming decades.

[4] The source of Figure 1.3 is UNEP (2008). The original source of is Arnell (2004).

Figure 1.3: Change in water availability compared with average 1961-1990 (%) 2050 based on IPCC scenarios A1

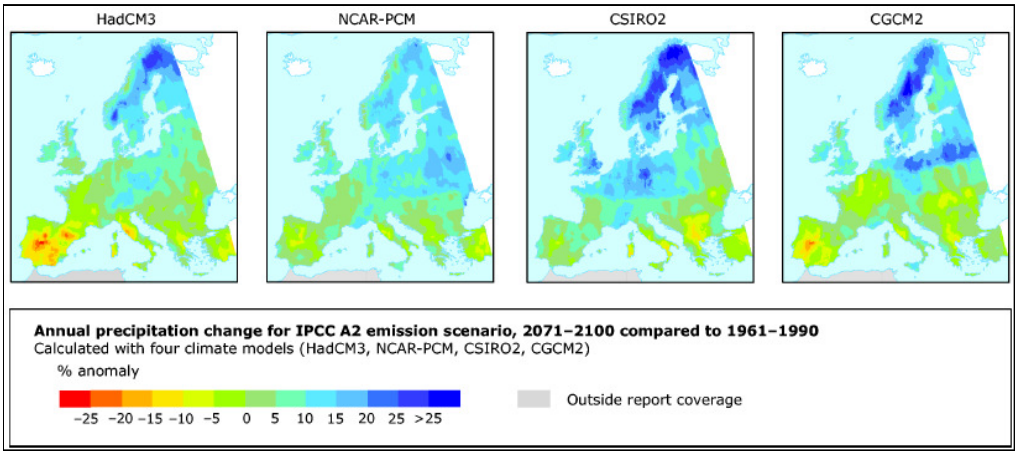


Recent reports from the European Environmental Agency on the impact of climate change indicate that the Iberian Peninsula is one of the European regions where the increase in temperature and decrease in rainfall and run-off will be most severe (EEA (2007*a*), p. 12; EEA (2007*b*), p. 155; EEA (2008), pp. 93-4, EEA (2009), p. 13), although because of the increase in the number of extreme weather events, the number of floods is also likely to increase in many parts of the Peninsula (EEA (2008), pp. 97-8)[5]. Figure 1.4 [6] shows the projected change in precipitation levels in Europe.

[5] UNEP (2007), p. 126, fig. 4.5 already reflects the declining precipitation in the south of the Iberian Peninsula as a 1900-2000 trend. Future reductions in precipitation and run-off are also reflected in the recent Intergovernmental Panel on Climate Change (IPCC) reports (see Kundzewicz, Mata, Arnell, Döll, Kabat, Jiménez, Miller, Oki, Sen and Shiklomanov (2007) and Bates, Kundzewicz, Wu and Palutikof (2008)). See also UNDP (2007), pp. 94-98, and UNEP (2007), chap. 4, pp. 115-156, for a description of the consequences of climate change on water stress and scarcity in the rest of the world. Arnell (2004) and Shen, Oki, Utsumi, Kanae and Hanasaki (2008) are more technical references regarding worldwide regional projections of water availability and water withdrawals, respectively.

[6] Copyright EEA, Copenhagen, 2007 (http://dataservice.eea.europa.eu/atlas/viewdata/viewpub.asp?id=2788). Figure 1.4 is Map 3.1. in EEA (2007*b*), p. 151. The original source of is Schröter, Cramer, Leemans, Prentice, Araújo, Arnell, Bondeau, Bugmann, Carter, Gracia, de la Vega-Leinert, Erhard, Ewert, Glendining, House, Kankaanpää, Klein, Lavorel, Lindner, Metzger, Meyer, Mitchell, Reginster, Rounsevell, Sabaté, Sitch, Smith, Smith, Smith, Sykes, Thonicke, Thuiller, Tuck, Zaehle and Zierl (2005). See Map

Figure 1.4: Changes in annual precipitation for the IPCC A2 scenario (2071–2100 compared with 1961–1990) for four different climate models



Explicitly referring to Portugal, the report points to "a change in the seasonal distribution of river flows, concentrating in winter months, induced by similar distribution patterns of precipitation. This trend exacerbates the seasonal asymmetry in the availability of water in continental Portugal, with a tendency for a reduction in river flows in spring, summer and autumn" (EEA (2007*a*), pp. 91-2), and refers that "the relative magnitude of the impact of climate change on river flows increases from the north to the south of the country" (EEA (2007*a*), p. 92). For 2030, a scenario is set out where the majority of the territory in mainland Portugal would face moderate or severe water stress[7], with the more worrisome levels being felt in inland Alentejo (EEA (2007*a*), p. 15, fig. 1.4) with consequences such as "diminished water quality, particularly in the south region (...), falling groundwater tables (...) [and] degradation of river ecosystems which are dependent on groundwater;" (EEA (2007*a*), p. 93) just to name a few. Portugal must, therefore, prepare for these more demanding scenarios[8].

3.3. in EEA (2007*b*), p. 155 for projected changes in annual river discharges.

[7] A region is considered to be under moderate water stress when water resources abstraction in each year represents between 20% and 40% of all water availability. Above this threshold the region is considered to be under severe water stress.

[8] The most important research concerning adaptation measures to climate change in Portugal is reflected in Santos, Forbes and Moita (2002) and Santos and Miranda (2006). Cunha, Oliveira and Nunes (2002) also includes forecasts for the impacts of climate change on the Portuguese water resources; its conclusions are similar to the ones drawn in the EEA and IPCC reports. The growing political importance of water scarcity

The management of water resources has been traditionally faced as a problem of insufficient supply to meet the existing and projected water requirements, with demand-side policies, such as incentive pricing being disregarded. Gradually the situation has been shifting and the discussion of water pricing policies is now essential.

The intervention of the economic regulator in Portugal (ERSAR - Entidade Reguladora dos Serviços das Águas e Resíduos, I.P. [Regulating Authority on Water and Waste Services], previously called IRAR - Instituto Regulador de Águas e Resíduos [Regulating Authority of Water and Waste]) remained limited to the municipal and multimunicipal concessions up to October 2009 (Baptista, Pássaro and Santos (2003) and Rouse (2007), p. 32), as established by article 4 of its previous Statutes (MA (1998) and MAOT (2002)), a situation which left room for the definition of water tariffs based on political criteria, instead of economic reasons. This is certainly one the main explanations for the diversity found in the tariffs. On October 2, 2009, the new organic and competences of ERSAR were approved (MAOTDR (2009)) after the institution itself in its new form having been already established in articles 5 and 21 of the Organic Law of the Ministry of Environment, Territorial Planning and Regional Development (MAOTDR (2006)). The main change brought with the change in the statutes of the economic regulator for the water industry in Portugal was the extension of its power to all water utilities in the country.

Nowadays, the analysis of the tariff policies is particularly important, given the requirements of the Water Framework Directive (WFD) (EU (2000)), which advocates an adequate integration of cost recovery concerns, including resource and environmental costs, in the tariff definition (article 9), until 2010, so that there are "adequate incentives for users to use water resources efficiently, and thereby contribute to the environmental objectives of this Directive".

The new Water Law (AR (2005)) transposes the WFD and imposes that "the pricing policy contributes to an efficient water use" (AR (2005), article 83^{rd}, e)). Article 78 establishes a water resources charge, which constitutes a first step towards the recovery

and drought and the greater recognition of the role of water pricing in Portugal, the European Union and other international organizations is reflected, for example in the following documents: MAOTDR (2007*b*); EC (2006), EC (2007*a*), EC (2007*c*), EC (2008*a*), UN-Water (2007) and UNDP (2006).

of scarcity/resource costs. The new Water Law also establishes in article 82 a set of objectives to be achieved with the tariffs, calling for the creation of a new tariff regulation applicable to all water utilities, which has meanwhile been drafted by ERSAR (ex-IRAR), but is still lacking final approval and publication by the government, after having been discussed with the industry stakeholders (MAOTDR (2008*b*)).

Setting up water tariffs can be a complex task, because this tool is usually meant to achieve several simultaneous goals, from efficiency in the use of this natural resource to the collection of enough revenues to guarantee the financial sustainability of the utility providing the service. Equity is also a concern, namely the definition of the adequate contribution from each type of consumer. The Portuguese water tariffs reflect this situation, sometimes reaching complexity levels which go beyond the will or capacity of the average consumer to understand them. The reasons for this complexity may be traced to the fact that water supply (WS) and wastewater drainage and treatment (WWDT) systems are typically capital-intensive with large infrastructures reflected in the large weight of fixed costs. Therefore, they are usually associated with scale economies and are considered local natural monopolies[9]. Because the consumer only has access to a single service provider and resale is tricky it is easy for the utilities to use price discrimination techniques[10]. The special nature of the good also causes its supply and treatment to be a service of general interest[11], reflected in obligations of public service like universal coverage, and its demand is usually rigid[12].

[9] The characteristics of the water industry which render it a natural monopoly, as well as the nature of the economic regulation for this type of industries, are described by Cardadeiro (2005).

[10] "Price discrimination involves selling different units of the same good at different prices, either to the same or different consumers" (Varian (1992), p. 241). We can distinguish three different types or degrees of price discrimination. First-degree price discrimination or perfect price discrimination consists of setting the price of each unit sold equal to the each consumer's maximum willingness to pay for that unit (the consumer surplus is appropriated by the monopoly). Second-degree price discrimination or nonlinear pricing is the practice of setting up a price schedule where prices differ for different amounts of the good bought, but not across consumers, which all face the same price schedule. Third-degree price discrimination is a pricing method where different consumers are charged different prices but where the unit price is constant for each customer class (for more details see Varian (1992)). We will see that water tariffs in Portugal are a combination of second and third-degrees of price discrimination.

[11] See EC (2003), EC (2004) and EC (2007*b*) for a definition of services of general interest as opposed to services of general economic interest. While the latter concept has been present in primary EU law, the former will be introduced by the Lisbon Treaty through a specific protocol (see EC (2007*b*) and EU (2007)).

[12] Price-elasticity of the Portuguese residential water demand has been estimated to be -0.558 by Martins

Given the importance of water tariffs, it is odd that there are so few studies analysing them in Portugal, namely regarding their structure and application. There are a few studies reporting the average level of Portuguese residential water tariffs, undertaken by the Portuguese Association of Water Distribution and Drainage[13] (APDA (2004) and APDA (2006)) and reflected in the Annual Reports on the Water and Waste Industry[14] published by IRAR (IRAR (2008*b*))[15]. The National Water Institute (INAG) did try to go beyond this basic analysis, publishing some information on the two types of tariff components (fixed and variable/volumetric) and on the number of blocks used (INAG/MAOTDR (2007); INAG/MAOTDR (2008); INAG/MAOTDR (2009)). However, none of these publications examines the impacts that the presence of blocks and the different calculation procedures may have on the average tariffs or on the marginal price faced by the consumer. These concepts are nevertheless essential to the study of the incentives transmitted by the tariffs to the consumer and which may or not lead to an efficient use of this scarce resource.

This chapter seeks to introduce this kind of economic rationality in the analysis of the Portuguese water and wastewater tariffs, looking in detail into their structure and its implications for the several types of final customer classes of the retail water utilities. To accomplish this task we use the data from the National Inventory on Water Supply and Wastewater Systems (INSAAR) for the years 1998, 2000, 2002 and 2005. Because this database has some missing data we complemented it with our own direct collection of information from all water and wastewater utilities in mainland Portugal in order to significantly fill in the missing data.

The actual water tariffs are compared with the main criteria for choosing a tariff scheme, emphasizing those which are associated with efficiency and the financial sustain-

---

and Fortunato (2007). Our own estimation is provided in Chapter 5.

[13] Associação Portuguesa de Distribuição e Drenagem de Águas (APDA).

[14] Relatórios Anuais do Sector das Águas e Resíduos (RASARP).

[15] IRAR (called ERSAR since October 2009) first used the data provided by APDA on the average tariff for an annual consumption of 120m^3 (IRAR (2007), vol. 1, pp. 27-34) and has now been reporting their own data using average values obtained by dividing total water revenues from sales to final users by the volume of water provided to final users (see IRAR (2008*b*), vol.2, pp. 35-7 and IRAR/LNEC (2007), p. 50, for the reporting of the formula used). The former approach of reporting tariff data for specific consumption levels has now been made available for each water utility on the Internet. See http://www.ersar.pt/xCelcius/ShowXCelcius_PopUp.aspx?FileName=/lib/6/11853C5B6963712724EE4B3F89FEC5F7A3212 for the 2007 tariffs.

ability of the utilities. From this comparison, a striking distance between efficiency and reality emerges.

1.2 Criteria for the analysis of a tariff scheme

Many authors have listed the objectives which guide the tariff policies in the water industry. Some useful references, which also deal with water tariffs in general are Hanemann (1997*b*), Agthe and Billings (2003), Shaw (2005), chap. 4, and Griffin (2006), chap. 8. Other references are Howe (2005) and Renzetti (2006) together with publications on the subject from international institutions such as the OECD (see OECD (1999*c*), OECD (2003*a*), OECD (2006) and OECD (2009)) and the UN (WWAP (2006), chap. 12 and UNDP (2006), chap, 2).

Next, we present the list of criteria for the analysis of a tariff system, taking into account the specificities of the water industry. Some of them are compatible but others are contradictory, which frequently imposes delicate choices (on the water utilities or the regulator). Each criterion is individually presented and in the end some important conclusions are drawn regarding the balance to be struck between them.

- Cost recovery: it is widely accepted that, in general, water utilities should seek balanced budgets as a required condition for the financial sustainability of the water industry. Therefore, the possibility to recover the costs of the activity through the revenues, from tariffs or elsewhere, is an important criterion of tariff analysis. This is a key element in economic regulation. The presence of this cost recovery principle in the current legislation (AR (2005), art. 3^{rd}, n.1, c)) has become on the one hand more stringent, by including environmental and resource/scarcity costs, and on the other hand more lenient by considering only an "adequate" contribution from the different users to achieve cost recovery (AR (2005), art. 83^{rd}, n.1, c)). To ensure cost recovery, it is necessary that the average price equals the average cost of providing the service. If it is lower, the water utility loses money and does not assure the future continuity of the service. If it is higher, the utility would be seizing a rent from its monopoly position, with the known accompanying welfare loss, particularly regarding the consumers' surplus.

- Economic efficiency: This criterion results from the economic nature of the potable water resource, reflecting its scarcity, i.e., the fact that it is a limited resource, available in insufficient quantities to meet the entire demand that it would face if it were a free access good, with a null price. Unlike the previous criterion, here we do not consider the balance between global revenues and costs, but between the cost of providing additional units of the good and their respective price, i.e., between the marginal cost and the marginal price. This is generally the condition which guarantees that net social benefit is maximized. It is easy to understand the important role that volumetric prices play in the consumers' decisions and which makes them an essential part of the price policy. As an example, compare two alternative tariffs, one where the cost is recovered through a fixed fee, whatever the amount of water consumed, and another where the cost is recovered through the charging of a price per m^3, where the consumers' water bills vary with the amount of water supplied. In the first case there is no indication given to the consumer about the value of the good, because the price of consuming an additional unit is zero. Naturally, consumption will be higher than the desirable efficient amount. In the second case, an incentive is transmitted to the consumer to use only the units from which a benefit can be drawn which is higher than the price charged. This is why a careful choice of volumetric prices is so important so that the consumer may have the correct signals on the value of the good being consumed.

It is convenient to clarify some aspects regarding what is considered to be efficient pricing. First, the efficiency criterion is in general concerned with the social benefit, as was mentioned above. This means that if there are any effects, which are external to the transaction between producer and consumer, and which generally do not have a monetary value associated, the efficiency rule requires that they are quantified and included in the calculation of the tariff. This is why the inclusion of the environmental and scarcity costs in the WFD and the corresponding national Water Law merits praise from the point of view of this criterion, even if the operationalization of these concepts is not straightforward.

A second feature of the efficiency principle is that the actual costs incurred are variable in time and space, because they depend heavily on the quantity and quality of the water available in the natural environment. This variability should, in principle, be reflected in the tariffs, but the resulting complication of the tariff system may object its consideration. One possible way of at least covering the cyclical variations in the scarcity of the resource is to create seasonal prices. Better yet would be their indexation to previously determined boundaries of water resources availability. In Portugal, the recently created water resources tax could play this role.

Third, the possible existence of increasing marginal costs does not justify the use of IBT. It is sufficient that the price equals the cost of the last unit supplied for the signal given to the consumer to be correct. Other justifications have to be found for the popularity of IBT in our country and elsewhere in the world[16]. Some motivations are pointed out in the 2006 Human Development Report of the United Nations, which states that "Block tariffs thus create the potential for aligning revenues with the costs of service provision, facilitating a sustainable financing model, while at the same time providing water for basic needs at below the cost of operations and maintenance." (UNDP (2006), pp. 84-5). Finally, the importance of a unit price does not imply that the existence of fixed charges is an inefficient practice, given that some of the costs may be specifically associated with the establishment or maintenance of an additional connection/customer, independently of the quantity supplied.

- Universal access: this is an easy to understand criterion, given the importance of water to human life and public health. No citizen should be denied, for economic or any other reason, the access to potable water and an effective wastewater drainage and treatment system. Evidently, this principle can be in conflict with the other aforementioned economic principles, but, in practice, there are many ways to bypass this problem like the implementation of an initial low priced block or the direct subsidization of low income families.

- Justice or equity: Cardadeiro (2005), p. 60, states "especially when dealing with the provision of services of general economic interest, it is totally irrealist to imagine that a tariff system could be applied, or even conceived, disregarding the issues of equity and social concerns"[17]. However, the main difficulty in applying this concept is that it can have

[16] The growing use of IBT in OECD countries is well documented in these organization's reports (OECD (2003*a*), p.70-73, and OECD (2009), pp. 100-101).

[17] Services of general economic interest are defined as "economic activities that public authorities identify

different meanings. One concept of justice frequently presented is that consumers with similar characteristics should pay similar prices, but if the costs of serving them differ this would be clearly inefficient and somewhat subjective (should we consider the household income, the type of housing, the household size or the existence of children and/or elders?). The use of different political criteria of justice is probably one of the main reasons for the complexity of the Portuguese water tariffs. Besides, an alternative concept of justice may be used, one which considers fair that each consumer be charged a price which reflects the cost of provision. The latter interpretation would be more compatible with the criteria of efficiency and cost recovery, but significant asymmetries could emerge between different groups of consumers, for example if they are located in different regions, something which may be politically undesirable[18].

- Simplicity: for tariffs to be understood by consumers, the impact of their decisions on the water bill should be made clear. A large number of blocks, especially combined with irregular meter readings, demanding adjustments in the water bill, make this comprehension more difficult. The existence of a constant unit price, not dependent on the volume consumed, is evidently the simplest volumetric price that can be implemented and it may even be efficient if the price is equal to a stable marginal cost. Simplicity is not only desirable for the consumer but it also facilitates an effective management by the water utilities, which may be harder to achieve with complex pricing schemes.

Summing up, a way to simultaneously ensure the desirable financial sustainability of water utilities and the no less desirable efficiency in the use of water resources is to set the unit price equal to the marginal cost and to adjust the fixed part of the tariff. The variable part of this two-part tariff provides the incentive for an efficient consumption while the fixed part would balance the utility's budget. An alternative, frequently used in the economic literature, is Ramsey pricing. According to this methodology, prices result from

as being of particular importance to citizens and that would not be supplied (or would be supplied under different conditions) if there were no public intervention" by the State Aid sub-Group of the Economic Advisory Group on Competition Policy (EAGCP (2006), p.1), which makes a clear association between this concept and the universal service obligations and explicitly includes water supply in the set of industries which the concept covers (EAGCP (2006), p. 2).

[18] For a description of the current political discussion in Portugal regarding the regional differences in water prices see Lopes (2008).

the maximization of the social benefit, bounded by the water utilities' budget balancing constraint. The solution to this problem consists of the establishment of different prices for different consumption quantities or types of consumers according to the price-elasticity of demand. This rule originates more complex tariffs and it may result in decreasing unit prices, which is not the case in the Portuguese water industry. It may however be especially useful if the flexibility to adjust the fixed part of the tariff is limited as seems to be the case in Portugal since the publication of Law n^o 12/2008 of February 26 (AR (2008)).

Universal access should be achieved with the minimum possible distortions in the prices charged to the majority of consumers and the final decision on the tariff schedule to be implemented should always consider the advantages associated with simplicity.

1.3 Portuguese water tariffs

Since 2002, INAG has been making available the INSAAR database. INSAAR compiles data on the WS and WWDT systems in Portugal. INSAAR differs from previous inventories in that it covers not only the physical infrastructure, stored in geographical information systems, but it also includes for the first time the main variables with economic relevance such as revenues and costs, investments, number of customers, volumes supplied/collected and the tariffs (Mendes, Avillez, Mendes, Gomes, Martins, Cardoso, Cardoso, Costa, Mendes, Robalo and Silva (2006)). This new feature tries to solve the problem identified by the National Water Plan in 2000 which recognized that at the time "the statistical information supporting the economic analysis of water uses is very poor" (Alves and Pinto (2004), 8.4).

The tariffs are collected from the water utilities with the necessary detail for economic analysis, because information is provided on the fixed and variable parts of the tariff, the existing blocks, their limits and respective prices and the formula used for the calculation of the final tariff. This is done separately for each of the sixteen types of customer classes considered. The detail in the database enables the rebuilding of the tariff in its entirety by the researcher and, for the first time in Portugal, the systematic calculation of marginal price levels, essential for an economic analysis which does not limit itself to the financial sustainability of the industry but that also focus on incentives present in the tariffs, going beyond the calculation of the average household water outlay. The only shortcoming in the database created by INAG is the significant amount of missing information resulting from a non-systematic and incomplete data reporting by the water utilities. Nevertheless, the mere existence and periodical update of the INSAAR database is a contribution to a cultural change towards the systematic gathering, storage, publication and availability of statistical information in Portugal and in the Portuguese water industry in particular.

1.3.1 Water supply tariffs

In this section, we will analyse the characteristics of the tariffs implemented in retail WS in 2005, based on the INSAAR data, for each of the customer classes available and we will show their evolution in the last few years. We will focus mainly on the residential tariffs, given that they represent the majority of the customers and volumes supplied at the retail level. The remaining customer classes will be analysed with reference to residential customers.

In fact, households represented 85.4% of the reported water meters[19]. If we consider only the meters for which the customer type was reported (which are 91.9% of all meters), the value rises to 92.9% (Figure 1.5). Residential customers also account for 70.4% of all reported volume and 75.1% of the volume for which the customer type was specified (Figure 1.6).

[19] Water meters are the measure for the number of WS customers in the INSAAR database.

Figure 1.5: Distribution of reported WS customers/meters by customer type (2005)

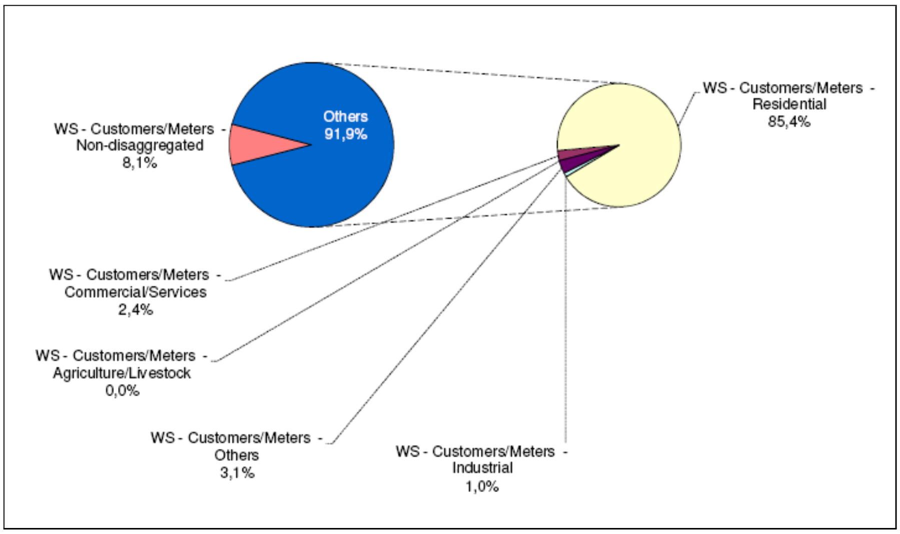
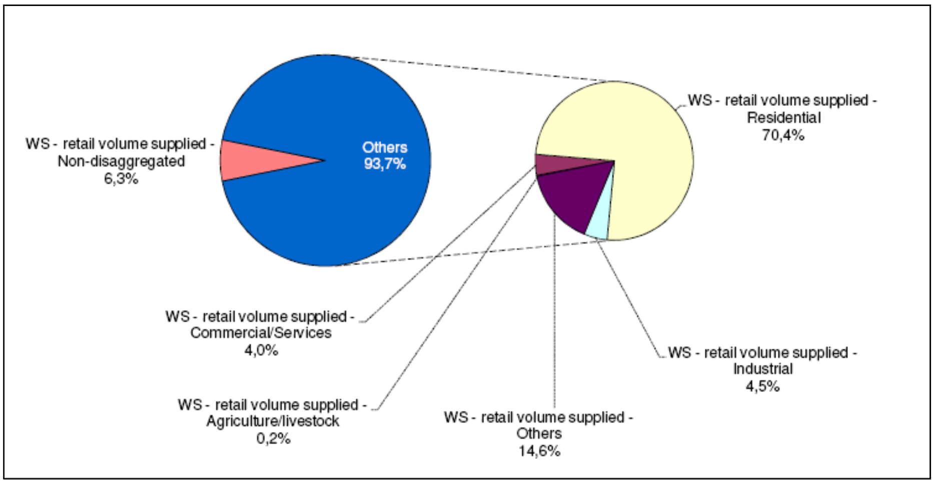


Figure 1.6: Distribution of reported retail WS volumes by customer type (2005)

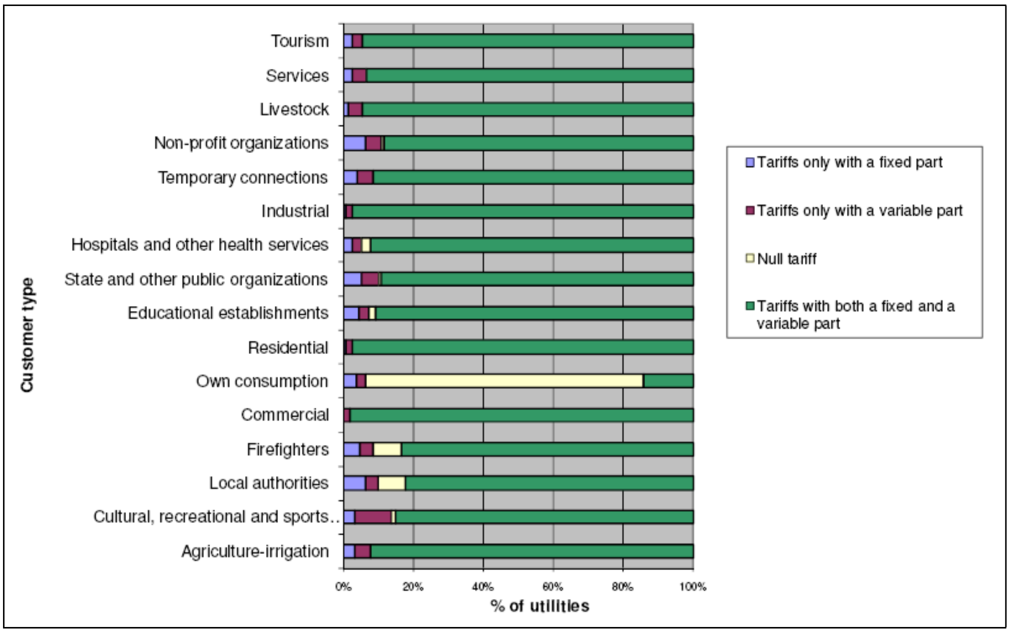


In 2005, information on the residential water tariffs was obtained from 263 water utilities. In 97.5% of the cases, the tariffs were composed of both a fixed and a volumetric part (Figure 1.7). For the remaining customer types[20], the value varied between 82%

[20] Here we look separately at all 16 customer types considered in INSAAR, but this does not mean that

(local authorities) and 98% (commercial and industrial customers), with the exception of the utilities' own consumptions for which no price is considered in the overwhelming majority of cases. Tariff exemptions are also found regarding local authorities, firefighters, education or health services and non-profit organizations, but in a much more reduced number of cases. Flat rates are also rare and may apply to the same types of customers.

Figure 1.7: Types of tariffs in WS by customer type (2005)

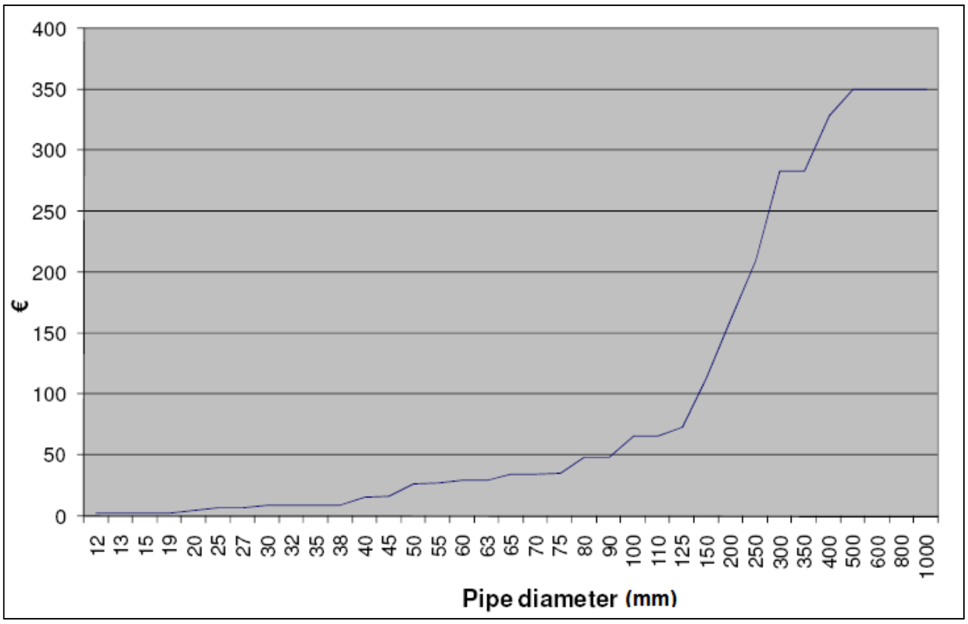


The fixed part of the tariff is an increasing function of the diameter of the pipe installed. Figure 1.8 shows the average value of the fixed part of the residential tariff by pipe diameter. It is a weighted average where the weight is the number of residential meters/customers in each water utility[21].

water utilities present this level of detail in their disaggregation of customer classes. Not a single one does. Only 8.2% separated at least 6 customer classes, while 64.3% used 3 at most. 17.5% of the utilities used the same tariff for all customer types. Charging the same tariff for the commercial and industrial customers or even to agricultural, livestock, services and touristic customers is common. Other customer types which usually face the same tariff are the educational, health and other state or local public services. The residential customers, temporary connections and own consumptions are the customer types which more often have their own separate tariff (or no tariff in the case of own consumptions).

[21] When the first value for the pipe diameter considered in the tariff is higher than 12mm, we assume its price applies to smaller diameters.

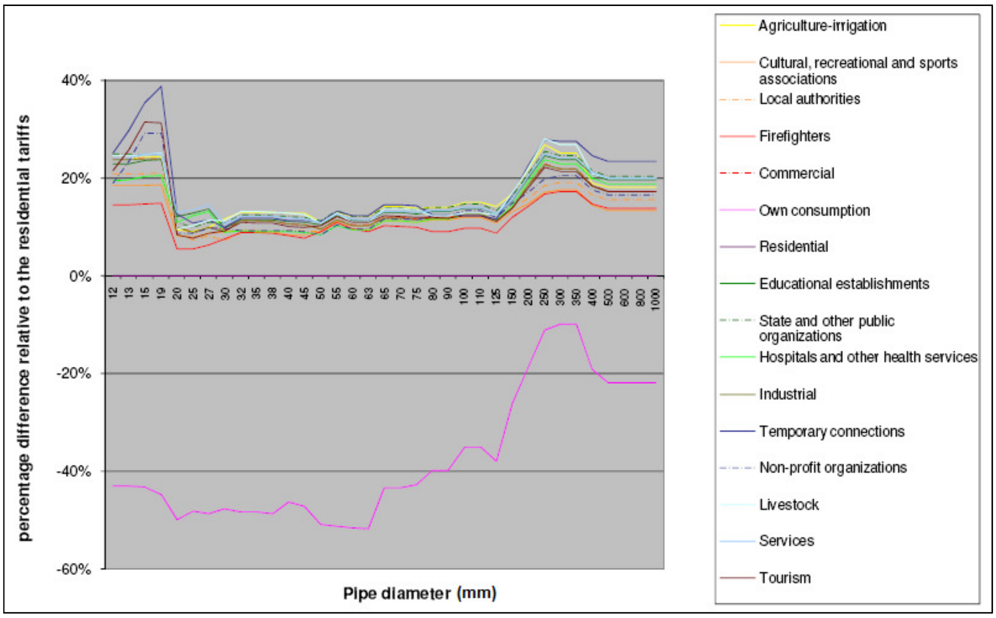
Figure 1.8: Fixed part of the residential WS tariff (2005) (average weighted by the number of residential meters)



Using the total number of meters as a common weight[22], we compare in Figure 1.9 the fixed part of the tariffs for different customer types relative to the residential tariffs as a percentage difference. We can see that the residential customers face lower fixed charges, whatever the diameter of the pipe installed, but more so in the smaller pipe diameters (which are more frequently used for households). Only own consumptions have an expected lower result. The other customer types face similar values, due to the fact that most utilities charge the same fixed charge for all non-residential customers. Due to some exceptions to this rule, the national average is slightly lower for some types of customers such as firefighters, local authorities and non-profit organizations or cultural, recreational and sports associations.

[22]The total number of meters is used to weight the tariffs of the different water utilities instead of the number of meters by each customer class, because in INSAAR, while the tariffs are disaggregated into sixteen different types of customers, the number of meters is only disaggregated into five different categories, one of them being the residual.

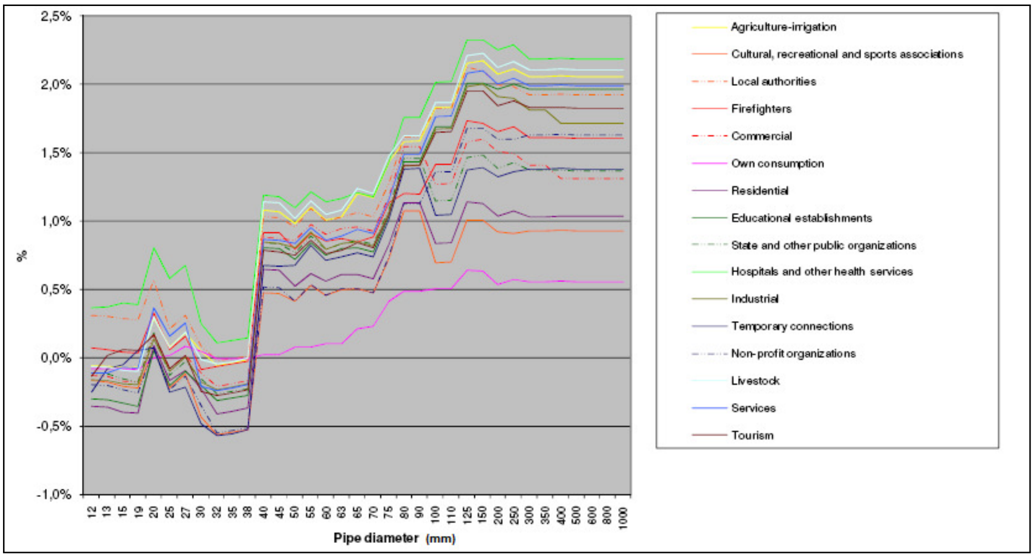
Figure 1.9: Percentage difference in the fixed part of the WS tariff relative to the residential customers by pipe diameter (average weighted by the total number of meters) (2005)



In the period 1998-2005, the tariff updates for the fixed part of the WS tariff have been lower than the inflation rate[23] for most customer types in the initial more relevant pipe diameters, generating a reduction in real terms of the payment for the fixed component of the tariff for most customers. For larger, less representative, pipe diameters, we find real increases in the range of 1.5-2.5%. Overall, the tariff updates may prove insufficient to keep up with inflation. For example, for residential customers, for a pipe diameter of 15mm (the most representative by far, with 73.4% of all residential meters), real prices fell on average 0.4% a year during the period 1998-2005.

[23] All monetary variables (expressed in Euros) are shown in 2005 constant prices (we used the Gross Domestic Product price deflator at market price for Portugal, unit Euro/ECU, provided by AMECO – Annual Macroeconomic Database, Directorate-General for Economic and Financial Affairs, European Commission).

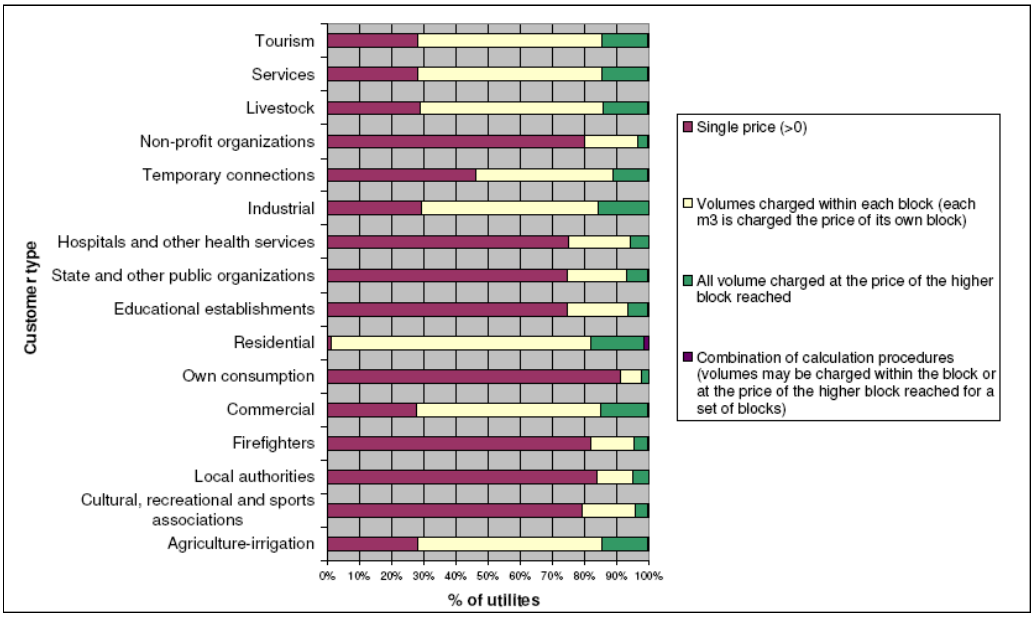
Figure 1.10: Average annual rate of change of the fixed part of the WS tariff by type of customer and pipe diameter (average weighted by the total number of meters) (1998-2005)



In the variable/volumetric part of the tariff, the use of IBT is common for the customer types associated with the main economic activities (agriculture, livestock, commercial, industrial, services and tourism), for households, where they are applied in 98.6% of the cases, and for temporary connections (Figure 1.11). For the remaining customer types, which are associated in one way or another to the provision of public services, the use of a single constant price per m^3 is more popular. More complex tariffs seem to be associated with economic activities which fall for the most part in the private sector and with households (the main customers of the public water supply network), while simpler tariffs are implemented for customer types with a strong presence of public entities and non-profit organizations.

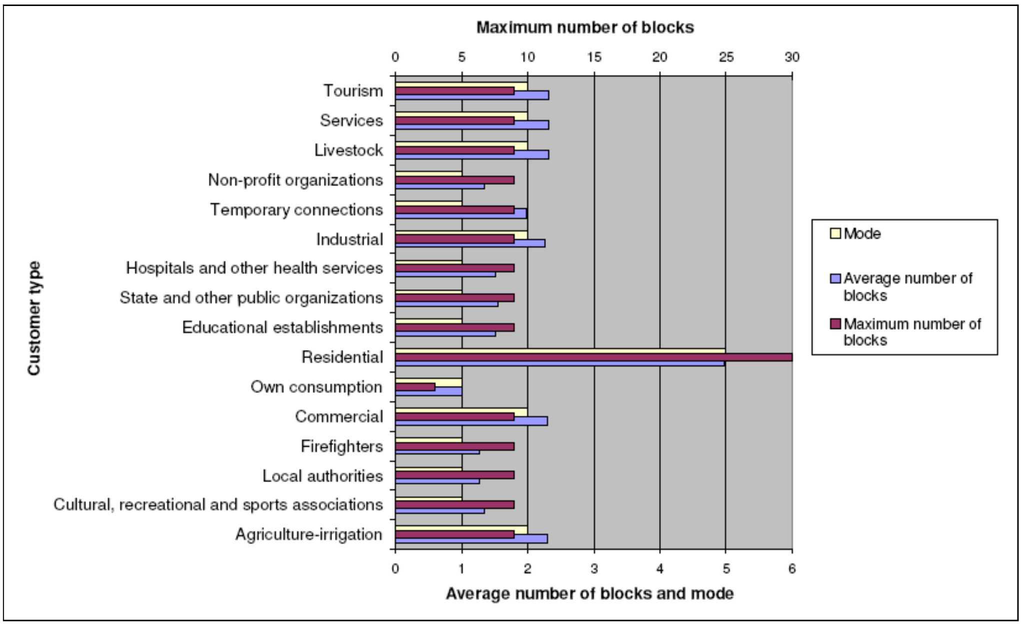
When the variable part of the tariff is made up of consumption blocks, the majority of the water utilities charge the volumes consumed at the price within each block. Nevertheless, in many cases, to compute the total value of the water bill, the price of the highest block reached is applied to all the volume consumed. This happens in 18% of the cases for households (including the water utilities which use a combination of calculation procedures). This way of computing the tariff does not seem to respond to any of the previously mentioned criteria for the definition of a water tariff scheme, except maybe the collection of additional revenues in a way which is less perceptible for the consumer. Efficiency and resource conservation are not promoted by this practice, because it does not reflect in the price the marginal cost of each unit consumed.

Figure 1.11: Types of volumetric components of WS tariffs by customer type (2005)



The average number of blocks used for residential customers is five, which is also the statistical mode, but many water utilities use a higher number of blocks which can be as high as thirty (Figure 1.12)! For the remaining customer types the average is between 1 and 2.3 and we find no case with more than nine blocks. The use of IBT may be an effective way to recover costs (in combination with the fixed part of the tariff), especially if the customers within each type are heterogeneous, but the reason why households must face more complex tariffs is not evident. The recent proposal for a tariff regulation establishes the use of a four blocks multi-part tariff for residential customers and a two-part tariff for the other customer types (MAOTDR (2008*b*), art. 17-25).

Figure 1.12: Number of blocks in the variable part of the WS tariff by customer type (2005)



We have seen in Figure 1.11 that one out of every six water utilities charges the price of the highest consumption block reached to all the volume consumed by residential customers. The use of this calculation procedure renders the marginal price faced by the consumer very irregular, with large spikes at the lower block limits. The marginal price for the first m^3 in each block may be several times higher than the previous and the subsequent m^3, because it includes not only its block rate also the difference between the rates of the current and the previous block multiplied by all the volume up to the lower block limit.

Table 1.1 shows this effect. It includes two similar hypothetical tariff structures, with the same number of blocks, with the same block ranges and the same price in each block. The only difference is the process used to compute the final value of the tariff. In tariff A, each m^3 is charged within the respective block of consumption while in tariff B the price of the highest block reached is charged to all the volume consumed.

We can see that the marginal price of the 6^{th} m^3 is almost three times higher than is

Table 1.1: Comparison of two different calculation procedures for a block tariff

Tariff	Blocks and prices				Marginal price (MP)		
Tariff A	Block	0-5 m^3	6-10 m^3	11-15 m^3	MP for the 5^{th} m^3	MP for the 6^{th} m^3	MP for the 7^{th} m^3
Each m^3 charged within the block	€/m^3	0.50	0.80	1.00	0.50	0.80	0.80
Tariff B	Block	0-5 m^3	6-10 m^3	11-15 m^3	MP for the 5^{th} m^3	MP for the 6^{th} m^3	MP for the 7^{th} m^3
The price of the highest block reached is charged to all volume	€/m^3	0.50	0.80	1.00	0.50	2.30	0.80

the case in tariff A, because it includes not only the €0.8 corresponding to the block price but also the price increase from the first to the second block multiplied by the first five cubic meters of consumption. This effect is not necessarily clear to the consumer from the information available in its water bill or even from the publicized tariff.

Figure 1.13 shows the weighted average for the average[24] and marginal prices practiced in the WS tariffs in mainland Portugal. The spikes in the marginal price are a result of the impact of the tariffs where the all volume is charged at the price of the highest block reached. The large number of spikes is due to the fact that the block limits are not necessarily coincident for all utilities. For the first few m^3 of consumption the average price is decreasing, due to the existence of the fixed part of the tariff, but the growing influence of the increasing variable part of the tariffs quickly renders the average price also increasing for higher levels of consumption (the inflexion point is at 10 m^3). Figure 1.13 also shows the weighted averages of the average tariff per m^3 disaggregated into its fixed[25] and variable part.

[24] The weight used to obtain the average values for the average and marginal prices in mainland Portugal was the retail volume of water supplied by each water utility. The previous qualifications regarding the different disaggregation levels in INSAAR for the customers relative to the tariffs also apply to the volumes.

[25] We use the 15mm pipe diameter to find the value for the fixed part of the tariff. This is the more frequently installed pipe diameter and it is the value used by APDA and INAG in their reports on the average Portuguese water tariff (APDA (2004), APDA (2006); INAG/MAOTDR (2005), INAG/MAOTDR (2007), INAG/MAOTDR (2008) and INAG/MAOTDR (2009)).

Figure 1.13: Marginal and average tariff for residential customers weighted by the retail volume of water supplied (2005)

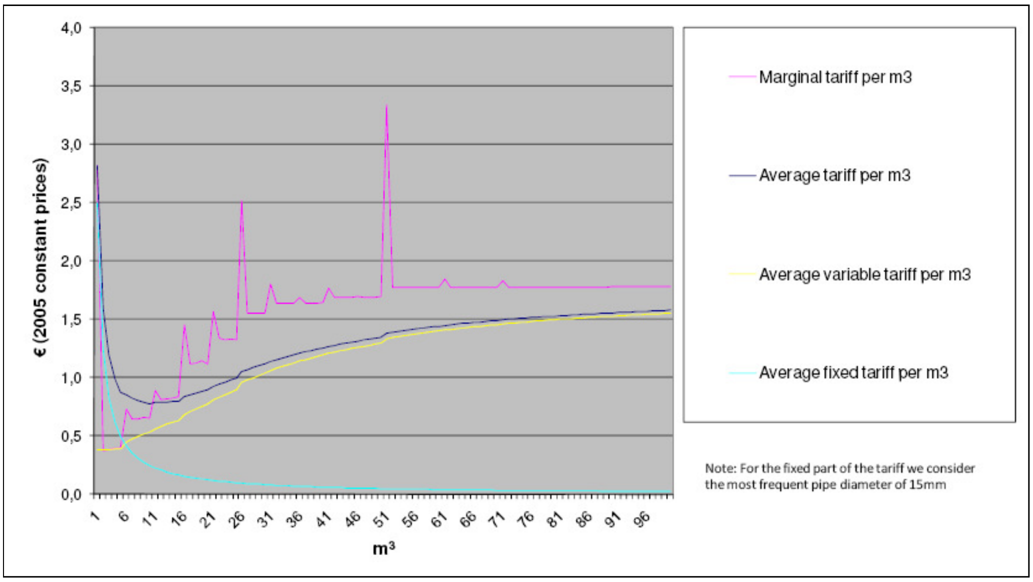


Figure 1.14 and Figure 1.15 illustrate the shapes of the average and marginal tariffs for two typical water utilities (with five consumption blocks), which differ in the way the final tariff is computed (one charges each volume within its block while the other applies the price of the highest block reached to all the volume consumed). Comparing both figures we can have a more correct idea of the size of the spikes in the marginal price caused by the tariff calculation procedure. Unlike Figure 1.13, where the spikes are mitigated by the averaging of all utilities, in Figure 1.15 we can see that the spikes increase exponentially with the volume consumed and make the marginal price for the units at the lower block limits several times larger than the block price.

Figure 1.14: Marginal and average tariff for a typical water utility (5 blocks and the volume charged within the block - the corresponding block price is charged to each m^3) (residential customers 2005)

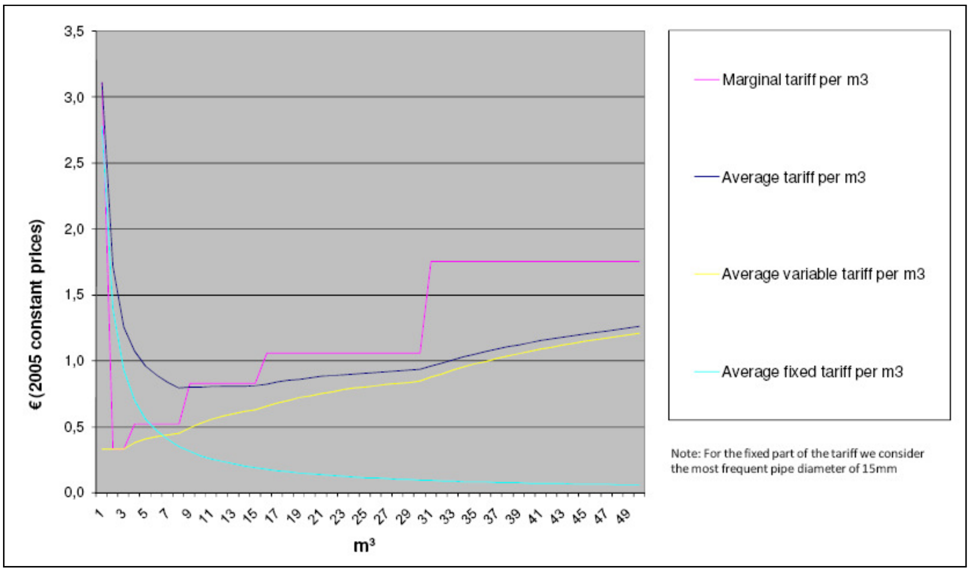
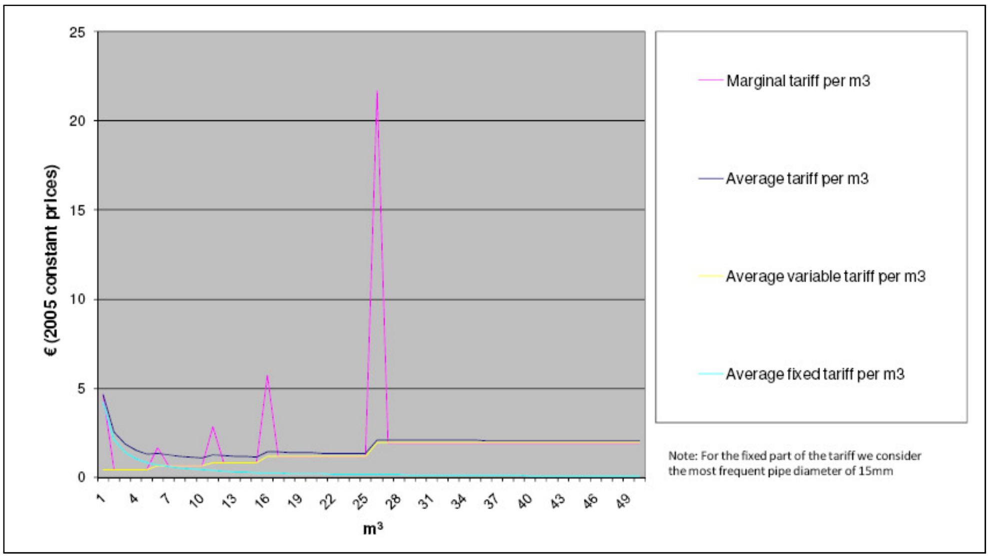


Figure 1.15: Marginal and average tariff for a typical water utility which charges all the volume at the price of the highest block reached (residential customers 2005)



Some WS tariffs include seasonal variations, which should not be surprising in Portugal given that the weather conditions, namely rainfall, show a significant seasonal variability. Besides, a large part of the Portuguese territory suffers frequent drought periods. However, only 2% of the water utilities use seasonal variations in the residential WS tariffs. Moreover, they are mainly located in the North and Centre regions of the country and many of them in the west coastal areas, which is odd given that it is in the South and East (inland) regions which face the more severe seasonal problems of water scarcity and droughts. In the tariffs which do have a seasonal differentiation, the summer tariff usually starts somewhere between May and July and lasts until September or October. The surcharges are between 30% and 50% of the base tariff, although in some extreme cases and in specific blocks they can be more than 3 times the base tariff. Usually, the lower blocks (the first 10 or 25 m^3) are exempted from the surcharge, which applies more commonly to the higher consumption blocks, which is not unreasonable given that lower volumes are associated with essential consumptions with little seasonal variation and which are much less price responsive.

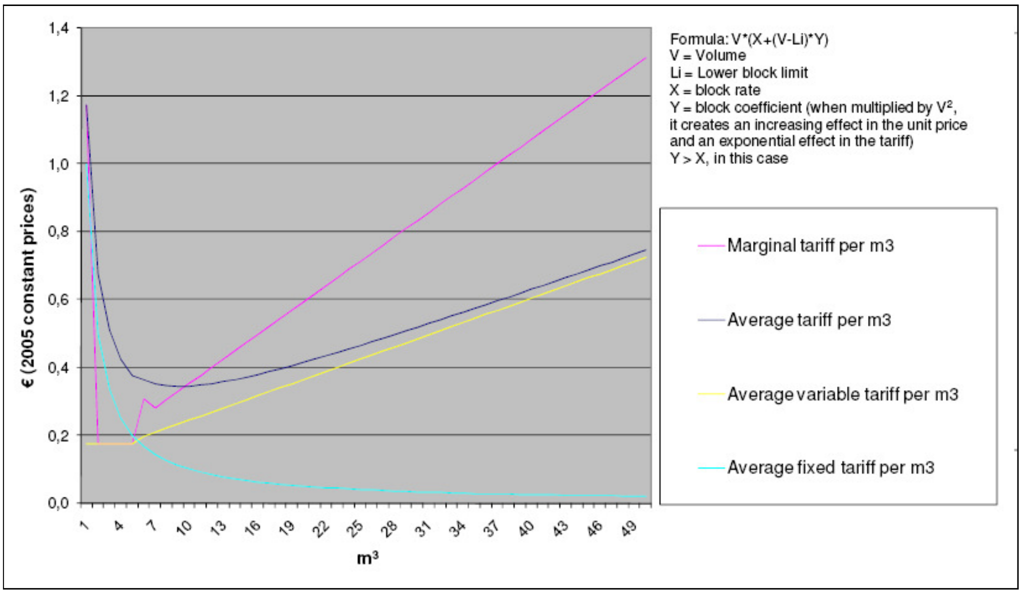
Adding to the presence of blocks and the possible existence of seasonality in the tariffs, water tariffs may have some additional complications, such as the existence of initial blocks with fixed charges, the implementation of formulas within each block, the existence of additional charges which are fixed within the block, but which vary between blocks and the existence of special contracts, such as social tariffs, for example.

Figure 1.16 demonstrates the impact caused by the use of formulas. In the case shown, there is a price of €0.18 for the first block (which covers the first five m^3). From then on[26] a formula of the type $V \times (X + (V - L_i) \times Y)$ applies (see the meaning of the variables used in Figure 1.16), whose objective is to make the marginal price increasing with consumption, generating a tariff which grows exponentially and which strongly discourages larger consumptions. This is an example of the implementation of continuous nonlinear pricing within this 2^{nd} block[27]. The implementation of this type of tariffs is rare.

[26] The spike in Figure 1.16 results from the process of charging all the volume consumed at the price of the highest block reached.

[27] The use of blocks is already a form of nonlinear pricing, because the price is not the same for all the units. However, the price is constant within each block. This is not the case in Figure 1.16, where we have

Figure 1.16: Marginal and average tariffs for a tariff schedule with the implementation of the formula V*(X+ (V-Li)*Y) (residential customers 2005)



The complexity in the tariffs led the National Water Institute to state that "it would be important to establish some guidelines which would help to harmonize the tariff computing methods" (Alves and Pinto, 2004, 8.4). This task was undertaken by IRAR (now called ERSAR), which put forward a proposal for a tariff regime, with the objective of standardizing and simplifying the existing tariffs (Santos (2006)). The new regulation will be applicable to all Portuguese water utilities (MAOTDR (2008*b*), art. 2) "public or private, concessionaries or otherwise, responsible for the management and operation of the municipal public water supply systems and/or public wastewater sewerage, as well as the entities responsible for approving the tariffs" (Santos (2006)).

The existence of special contracts for specific customers is not a rule, but is also not rare and it is easy to find examples of its use (Table 1.2 and Table 1.3)[28]. These types of contracts affect more frequently the variable part of the tariff. The customer types

nonlinear prices even within the blocks. This is what we are terming continuous nonlinear pricing.

[28] Table 1.2 and Table 1.3 refer to the year 2002, because this is the year were INSAAR provides more complete and detailed data. Our additional efforts to fill in missing data were focused on the normal tariffs and not on special contracts.

which are benefited more often are the educational establishments for the first cycle of basic education (primary schools, up to the 4^{th} grade) and the residential customers (with a few exceptional situations for the employees/officials of the water utility, for urbanizations or customers outside the municipal county's borders and exemptions for the first m^3 consumed). For the remaining customer types we find the most varied examples of special contracts, from tariffs differentiated by civil parish to special tariffs for hotels, restaurants, churches and sanctuaries, fairs and expositions, cemeteries, railways, private social solidarity institutions, State institutions, or soccer clubs. Specifically regarding the variable part of the tariff, a special tariff for water breaks is common.

Table 1.2: Frequency and motive for the use of special contracts regarding the fixed part of the retail WS tariff (2002)

Customer type	Number of cases	Motives
Agriculture-irrigation	0	-
Cultural, recreational and sports associations	1	Sports associations
Local authorities	2	Street washing; pools
Firefighters	0	-
Commercial	1	Tariffs differentiated by civil parish
Own consumption	0	-
Residential	6	Tariffs differentiated by civil parish; municipality officials; urbanizations; areas outside the municipal county's borders
Educational establishments	14	1st cycle of basic education (up to the 4^{th} grade)
State and other public organizations	5	Security forces, courts
Hospitals and other health services	0	-
Industrial	1	Tariffs differentiated by civil parish
Temporary connections	3	Tariffs differentiated by civil parish; fairs; expositions
Non-profit organizations	0	-
Livestock	0	-
Services	2	Tariffs differentiated by civil parish; railways
Tourism	2	Tariffs differentiated by civil parish; specific hotel

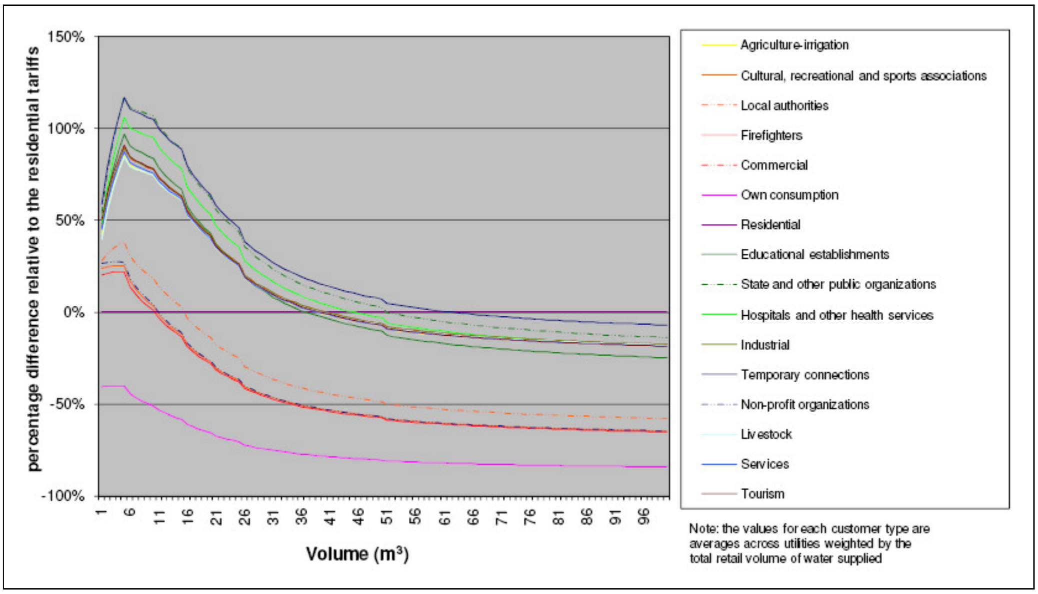
Table 1.3: Frequency and motive for the use of special contracts regarding the variable part of the retail WS tariff (2002)

Customer type	Number of cases	Motives
Agriculture-irrigation	3	Exemption for the first 26 m^3; breaks
Cultural, recreational and sports associations	1	Sports associations; for-profit organizations; specific soccer club; breaks
Local authorities	12	Civil parishes; street washing; pools; irrigation of public gardens; breaks
Firefighters	0	-
Commercial	8	Tariffs differentiated by civil parish; food and beverage establishments and the like; breaks
Own consumption	0	-
Residential	35	Tariffs differentiated by civil parish; officials from the municipality, civil parish or the autonomous municipal services; private garages; exemptions for the first 5-130 m^3; patios; breaks; rural; urbanizations; areas outside the municipal county's borders
Educational establishments	65	1st cycle of basic education (up to the 4th grade); secondary education; breaks
State and other public organizations	23	Military bases; Regional Agricultural Office; public companies; security forces; central public organizations; breaks; social security; courts
Hospitals and other health services	1	Exemption for the first 13 m^3
Industrial	18	Tariffs differentiated by civil parish; wine cooperatives; raw water; agri-food industry cooperatives; olive oil mills; breaks; industrial units located in industrial parks
Temporary connections	11	Tariffs differentiated by civil parish; fairs; expositions; markets; cemeteries
Non-profit organizations	16	Churches; institutions of public utility of any kind; private social solidarity institutions (IPSS); exemption for the first 26 m^3; breaks; Santa Casa da Misericórdia; sanctuary
Livestock	2	Breaks
Services	3	Tariffs differentiated by civil parish; railways; breaks
Tourism	3	Tariffs differentiated by civil parish; specific hotel

We take a look now at the average weighted value[29] of the average variable part of the tariff applied to each customer type and compare it with the values for the residential customers' tariffs. Figure 1.17 shows that for the initial 10 m^3 only own consumptions show a lower value than the residential customers. In fact, besides facing a lower charge in the fixed part of the tariff (as we have seen in Figure 1.9), residential customers also benefit from lower unit prices for the initial m^3 of water consumed. Even customers like cultural, recreational and sports associations, non-profit organizations, firefighters and local authorities face average volumetric tariffs which may be up to 25%, 27%, 22% and 38% higher, respectively. For the remaining customer types the difference may be even larger (up to 85%-118%). There is a clear intention to provide the residential customers with a minimum amount of water at a more affordable price. From the 5^{th} m^3 (which is usually the upper limit for the first residential block) onward, the impact of the increasing block prices makes its impact felt more intensively for residential customers and their advantage regarding other customer types begins to wane and is even inverted for higher levels of consumption.

[29] The weight used is the total retail WS volume of water supplied by each water utility.

Figure 1.17: Percentage difference in the variable part of the WS tariff relative to the residential customers (average weighted by the total volume supplied) (2005)



The existence of a fixed part in the water tariffs makes the average tariff strongly decreasing in the first 10m^3 (Figure 1.18), after which the average residential tariff becomes significantly increasing. This decreasing trend is eventually also inverted for the customer types associated with private economic activities like agriculture, livestock, commercial, industrial, services and tourism (with inflection points between 30 and 50 m^3), but the inversion is much more pronounced in the residential tariffs due to the greater number of blocks.

Figure 1.18: Average tariff per m^3 in WS by customer type (2005)

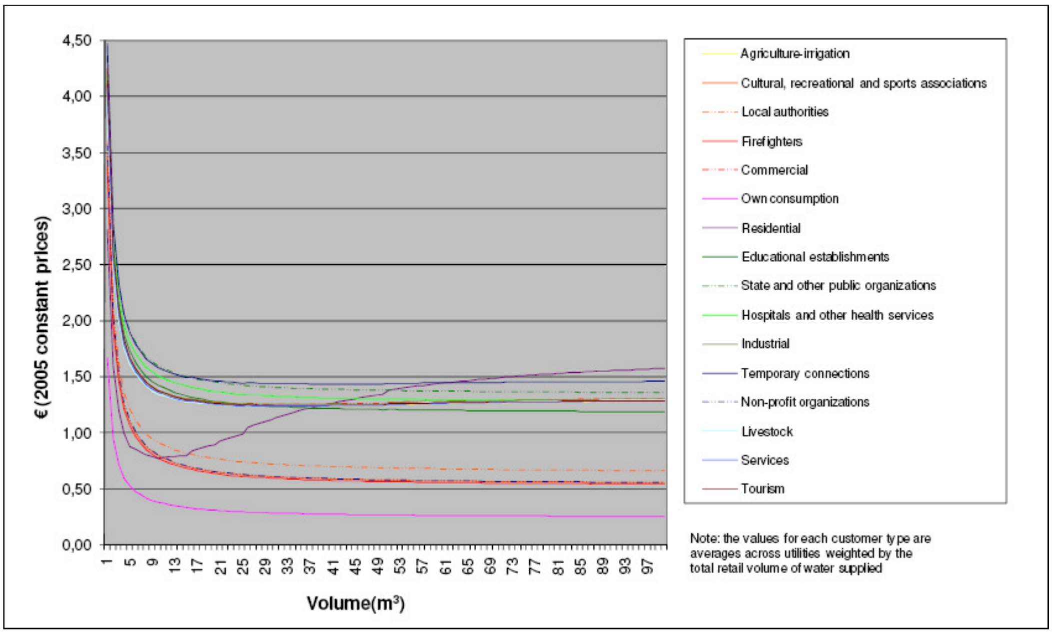
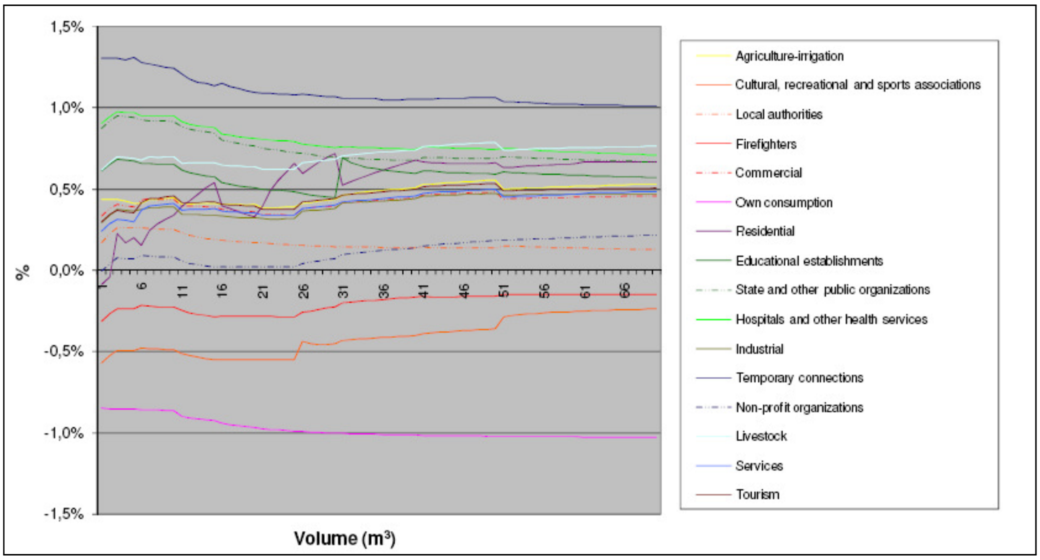


Figure 1.10 showed the average annual rate of change in the period 1998-2005 in the fixed part of the WS tariff. Figure 1.19 does the same for the variable part for the several types of customers. We can see that, with few exceptions the real growth rates in this part of the tariffs were between 0% and 1% a year. Temporary connections had slightly higher price increases, while firefighters, own consumptions and cultural, recreational and sports associations benefited from real price reductions. Regarding residential customers it is noticeable that price increases were slightly lower for the initial m^3 of consumption. Overall, there seems to be some stability in the level of WS tariffs, with slight increases in the variable part compensating small decreases in the fixed part for relevant pipe diameters. Nevertheless, the tariffs do not seem to have kept up with cost increases as INAG reports cost recovery levels in WS to have changed from 99% in 2002 to 87% in 2005, 89% in 2006 and 84% in 2008 (INAG/MAOTDR (2005), INAG/MAOTDR (2007), INAG/MAOTDR (2008) and INAG/MAOTDR (2009))[30].

[30] We must caution that the INSAAR calculations refer to a different time period, also include bulk water suppliers and obviously also consider the cost side of the water supplying activity, so that our 1998-2005 growth rates calculation may have very little association with the variation in the cost recovery levels

Figure 1.19: Average annual rate of change of the variable part of the WS tariff by type of customer (average weighted by the volume of retail water supplied) (1998-2005)



The approach followed so far of basing the analysis on the entire rate structure has enabled us to go beyond the traditional approach of computing the average tariff for pre-established consumption levels, but this latter approach also has its advantages, namely for regional analysis. We shall focus here on the residential customers, considering the usual reference values: average monthly consumption of 10 m^3 uniformly spread throughout the year, and a pipe diameter of 15 mm. The final results for the NUTS III subregions are obtained using the retail volume of water supplied by each water utility as a weight. Figure 1.20 shows that the higher tariffs are found in general in the urban coastal regions to the north of the Sado river (namely around the two metropolitan areas of Lisbon and Oporto) and in Beira Interior. The regional disparity in the tariffs is one more motive besides their complexity calling for the implementation of a tariff regulation. This is recognized in European reports, when they state that "there are great disparities in tariffs for urban supply, throughout the municipalities, but the Institute for Regulation (IRAR) is establishing a reference model for tariff revision, taking into account principles of cost recovery and equity" (EEA (2007*a*), p. 94).

reported by INAG. Chapter 2 presents a detailed analysis of cost recovery levels in Portugal.

Figure 1.20: Average tariff for a monthly consumption of 10m^3 by a residential customer disaggregated at the NUTS III sub regional level (1998-2005)

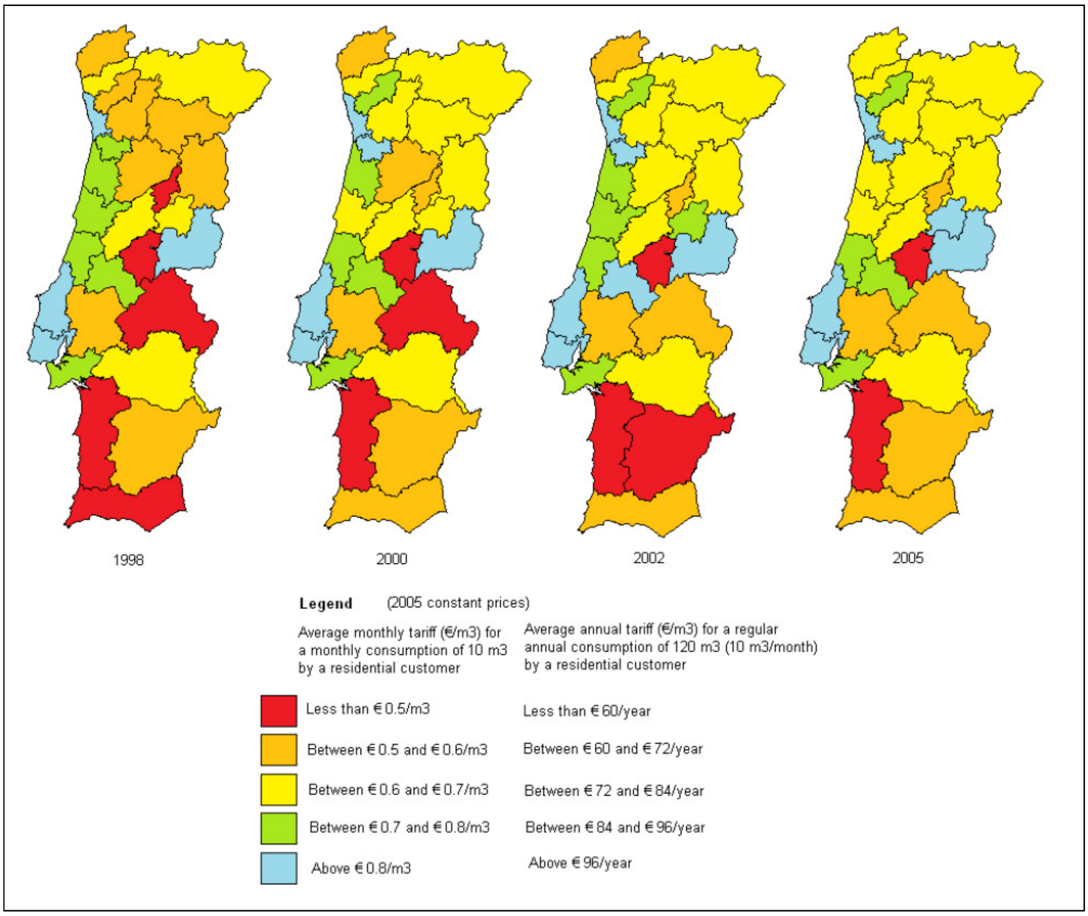


Table 1.4 presents the results of the same method applied to compare the average tariffs for the several types of water utilities. The highest average tariffs are found in autonomous municipal services, followed by private companies. The lowest values are practiced by the municipalities. Public and municipal companies have intermediate values. Because the autonomous municipal services constitute a type of management in-between the operation of the service by the municipality itself and the creation of public companies to run it or even the concession of the service to privately owned businesses, we are unable to find conclusive evidences regarding any type of relationship between the type of utility (type of management and ownership) and the average value of the tariff faced by the residential

customer. The differences in the values for the average residential tariffs seem to be more associated with the location of the utilities than with their management type (the types of utilities which have higher tariffs are also the ones which are predominantly located in the more urban and densely populated regions (autonomous municipal services, private companies, municipal companies)[31]. Table 1.5 shows the large ranges of variations in the tariffs implemented by each of the types of utilities.

Table 1.4: Average tariff for a regular monthly consumption of 10 m3 by residential customers disaggregated by type of utility (2002-2005)

Type of water utility	Average monthly tariff (€/m^3) for a monthly consumption of 10 m^3 by residential customers		Average annual tariff (€/year) for a regular annual consumption of 120 m^3 (10 m^3/month) by residential customers	
	2002	2005	2002	2005
Municipality	0.61	0.62	72.9	74.3
Autonomous Municipal Services	0.95	0.94	114.0	112.7
Municipal or Intermunicipal Company	0.76	0.71	91.2	85.5
Public Company	0.69	0.70	82.5	84.6
Private Company	0.89	0.90	107.1	107.7

Table 1.5: Range of variation of the tariff for a regular monthly consumption of 10 m3 by residential customers disaggregated by type of utility (2002-2005)

Type of water utility	Average monthly tariff (€/m^3) for a monthly consumption of 10 m^3 by residential customers		Average annual tariff (€/year) for a regular annual consumption of 120 m^3 (10 m^3/month) by residential customers	
	2002	2005	2002	2005
Municipality	0.13 – 1.16	0.09 – 1.22	15.0 – 139.7	11.1 – 146.3
Autonomous Municipal Services	0.48 – 1.15	0.52 – 1.19	57.7 – 138.5	62.5 – 143.0
Municipal or Intermunicipal Company	0.13 – 1.30	0.49 – 1.38	15.0 – 156.0	58.5 – 165.8
Public Company	0.35 – 0.92	0.37 – 0.91	42.5 – 110.2	44.3 – 109.1
Private Company	0.27 – 1.32	0.29 – 1.22	32.4 – 158.5	35.1 – 146.4
Total	0.13 – 1.32	0.09 – 1.38	15.0 – 158.5	11.1 – 165.8

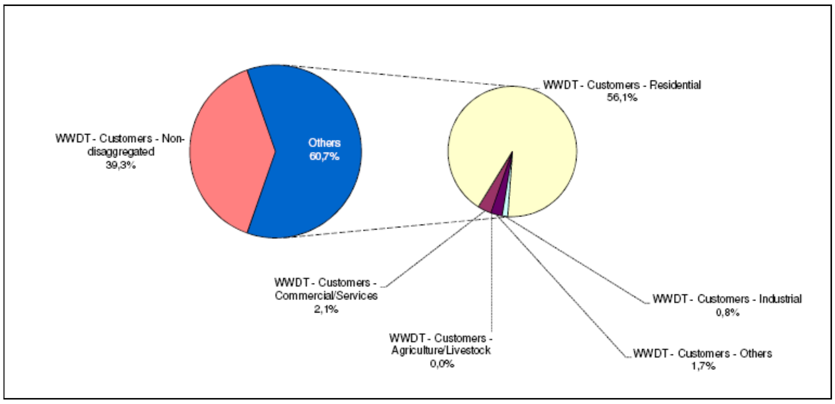
[31] For an example of a more thorough empirical investigation into the relationship between utility ownerhip and the water price level for the Spanish case see Martínez-Espiñeira, García-Valiñas and González-Gómez (2009). This study does find a positive and significant effect of private ownership on prices.

1.3.2 Wastewater drainage and treatment tariffs

For the analysis of the tariffs to be complete we must also look at the sewerage tariffs which appear in the water bill together with the tariffs charged for the water supply. The WWDT charges bring additional complexity to the tariffs, namely the fact that the calculation of the value of the tariff may sometimes depend on factors other than the volume of wastewater drained or the volume of water supplied does not enable us to carry out the analysis with the same level of detail as we did for WS tariffs. In particular, we will not compute the average WWDT tariff because the result could be biased if we chose to do it only with the utilities which base their tariff on the water consumption values. Nevertheless, we will describe the main characteristics of the Portuguese WWDT tariffs.

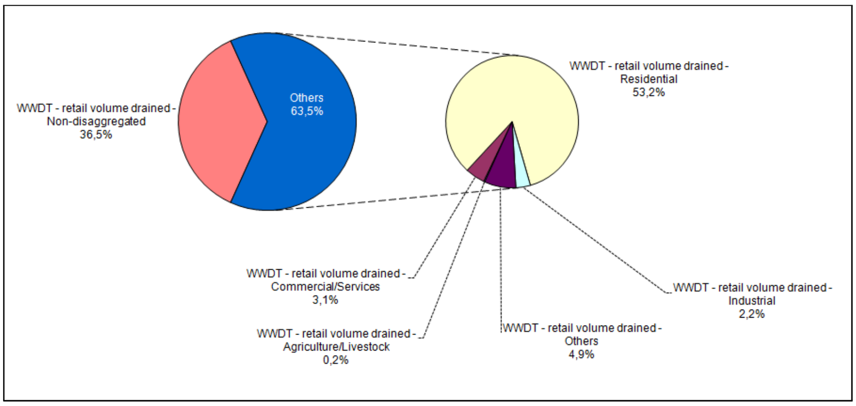
Like we did for the water supply, we shall focus on residential customers, because they represent the large majority of customers and volumes drained reported to INSAAR and disaggregated by type of customer by the wastewater utilities. We can see from Figure 1.21 that 60.7% of the reported WWDT customers were disaggregated by customer type by the utilities. Of those, 92.3% were households.

Figure 1.21: Distribution of reported WWDT customers by customer type (2005)



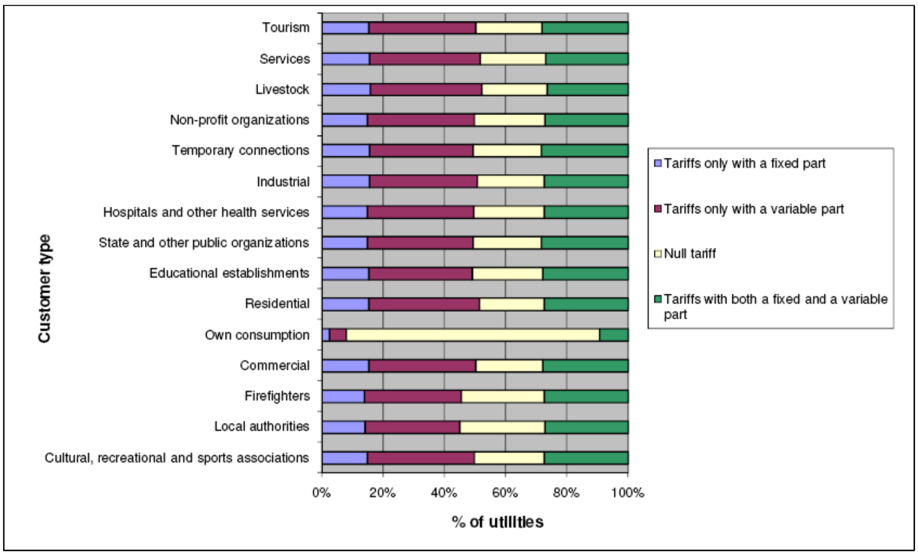
Households were also responsible for 83.7% of the wastewater drained reported to INSAAR and disaggregated by customer type, which accounts for 60.7% of the total (Figure 1.22).

Figure 1.22: Distribution of reported wastewater volume drained by customer type (2005)



From Figure 1.23, we can see that in 2005 the most common situation for WWDT tariffs was the inclusion of only a variable part of the tariff by around 1/3 of the utilities for every customer type, with the exception of own consumptions which are for the most part exempt. The situation which we consider more correct of applying both a fixed and a volumetric part is also applied in a reasonable proportion of utilities (26%-28% of utilities in all customer types, except own consumption, which is a significant increase regarding the values for 1998 which were lower than 15%). 14%-16% of utilities only include a fixed part in the WWDT tariff and a very significant percentage of utilities did not charge anything for the sewerage service (21%-28%, according to the customer type, with the exception of own consumption).

Figure 1.23: Types of WWDT tariffs by customer type (2005)



Generally, the fixed part of the WWDT tariff can be a fixed charge or it can depend on the water pipe diameter, the gross or usable construction area, the taxable income or the real estate value of the building being served (Table 1.6[32]). Certain special contracts may make this part of the tariff dependent on the number of employees for certain economic activities, on the household size or the number of bedrooms or beds for households. The number of days of use can also be a base for the fixed part of the tariff concerning pre-treated industrial wastewater.

To compute this part of the WWDT tariff, a specific coefficient is multiplied by the value of the base variable, but the presence of blocks is not uncommon, with different coefficients for different ranges of the base variable.

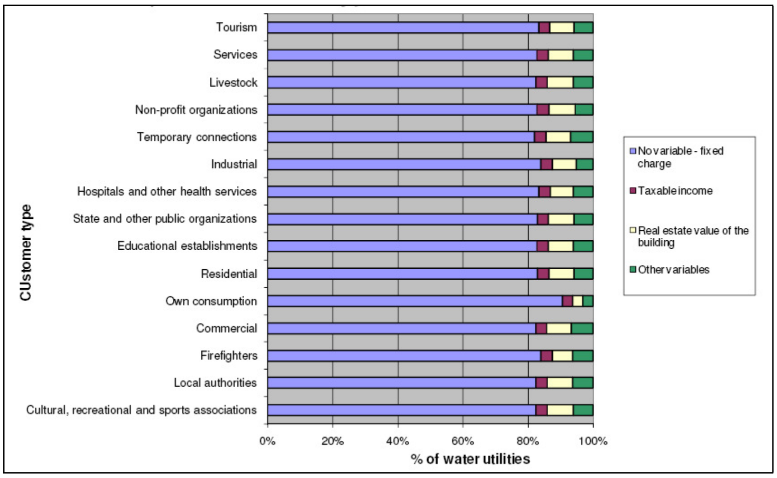
[32] SC stands for special contracts.

Table 1.6: Base variables for the fixed part of the wastewater drainage and treatment tariff (1998-2005)

Customer type	No variable, fixed charge	Water pipe diameter (mm)	Gross construction area (m^2)	Usable construction area (m^2)	Number of beds	Number of days
Cultural, recreational and sports associations	X	X	X	X	-	-
Local authorities	X	X	X	X	-	-
Firefighters	X	X	X	X	-	-
Commercial	X	X	X	X	-	-
Own consumption	X	X	X	-	-	-
Residential	X	X	-	-	X	-
Educational establishments	X	X	X	X	-	-
State and other public organizations	X	X	X	X	-	-
Hospitals and other health services	X	X	X	X	-	-
Industrial	X	X	X	X	-	X
Temporary connections	X	X	X	X	-	-
Non-profit organizations	X	X	X	X	-	-
Livestock	X	X	X	X	-	-
Services and Tourism	X	X	X	X	-	-
Customer type	Household size	Number of employees	Number of bedrooms	Taxable income	Real estate value of the building	
Cultural, recreational and sports associations	-	X (only SC)	-	X	X	
Local authorities	-	-	-	X	X	
Firefighters	-	-	-	X	X	
Commercial	-	X (only SC)	-	X	X	
Own consumption	-	-	-	X	X	
Residential	X (only SC)	-	X (only SC)	X	X	
Educational establishments	-	-	-	X	X	
State and other public organizations	-	-	-	X	X	
Hospitals and other health services	-	-	-	X	X	
Industrial	-	X	-	X	X	
Temporary connections	-	-	-	X	X	
Non-profit organizations	-	X (only SC)	-	X	X	
Livestock	-	-	-	X	X	
Services and Tourism	-	-	-	X	X	

The solution most widely implemented by the WWDT utilities is to set a fixed charge per billing period without a reference variable (Figure 1.24). The use a fixed charge increased in the period 1998-2005. However, the use of taxable income or the real estate value of the property as a reference variable can also be found in many cases. The remaining possibilities are rarer.

Figure 1.24: Base variables for the fixed part of the wastewater drainage and treatment tariff (2005)



The variable/volumetric part of the tariff, when implemented, is more often made dependent on the amount of water consumed (83%-88% of the cases, according to the customer type). Just like in the WS case, some utilities may include consumption blocks in the WWDT tariffs, and they may use the previously mentioned methods for computing the final tariff: charging the volumes within each block or charging the price of the highest block reached to the entire volume of wastewater produced. Nevertheless, in the great majority of the cases a constant price per m^3 is applied. In 13%-17% of the cases, according to the customer type, the value of the variable part of the WWDT tariff is computed as a percentage of the value of the WS tariff. The percentages used vary from 10% to 65%. There are two other possibilities, which are the use of the amount of wastewater drained or the pollutant load of the effluent as a reference variable, but these cases are rather rare and are usually the subject of special contracts for specific industries.

We can also find in the wastewater tariffs several cases where special contracts are established for the most varied reasons as Tables 1.7 and 1.8 document[33]. Some of the motives are similar to what we have seen for the WS tariffs, like the establishment of special contracts for the employees of the water utilities, for private social solidarity institutions, State organizations and others. Other motives are specific to the sewerage activity, the most common of them being the separation of the WWDT customers which do not benefit from the WS service (we have seen before that most of the times the WWDT tariff is indirectly based on the WS tariff). Sometimes there are also special contracts for the cases where the wastewater is discharged into the public system with some level of previous treatment.

[33] Tables 1.7 and 1.8 refer to the year 2002, because this is the year were INSAAR provides more complete and detailed data. Our additional efforts to fill in missing data were focused on the normal tariffs and not on special contracts.

Table 1.7: Frequency and motive for the use of special contracts regarding the fixed part of the retail WWDT tariff (2002)

Customer type	Number of cases	Motives
Agriculture-irrigation	0	-
Cultural, recreational and sports associations	1	Sports associations
Local authorities	1	Customers without WS service
Firefighters	0	-
Commercial	12	Customers without WS service; food and beverage establishments; commercial areas with a covered surface greater than 200 m^2
Own consumption	0	-
Residential	15	Customers without WS service; urbanizations; areas outside the municipal county's borders
Educational establishments	3	1st cycle of basic education (up to the 4^{th} grade)
State and other public organizations	3	Customers without WS service; Regional Agricultural Office; security forces
Hospitals and other health services	0	-
Industrial	14	Customers without WS service; treated water; pre-treated water; only domestic effluents
Temporary connections	2	Customers without WS service; fairs; expositions
Non-profit organizations	3	Customers without WS service; churches; private social solidarity institutions (IPSS)
Livestock	0	-
Services	0	-
Tourism	3	Customers without WS service; hotels

Table 1.8: Frequency and motive for the use of special contracts regarding the variable part of the retail WWDT tariff

Customer type	Number of cases	Motives
Agriculture-irrigation	0	-
Cultural, recreational and sports associations	2	For-profit associations
Local authorities	0	-
Firefighters	0	-
Commercial	2	Direct discharge in the wastewater treatment plant
Own consumption	0	-
Residential	8	Officials from the municipality, civil parish or the autonomous municipal services; urbanizations; areas outside the municipal county's borders
Educational establishments	6	1st cycle of basic education (up to the 4^{th} grade)
State and other public organizations	4	Regional Agricultural Office; public companies; security forces; social security; courts
Hospitals and other health services	0	-
Industrial	4	Treated wastewater; only domestic effluents; pollutant load
Temporary connections	2	Fairs; expositions; markets; cemeteries
Non-profit organizations	3	Private social solidarity institutions (IPSS)
Livestock	0	-
Services	0	-
Tourism	0	-

1.4 Conclusion

The main conclusion to be drawn from the analysis of the Portuguese water and wastewater tariffs is that they are far from simple, especially regarding the residential customers. Nevertheless, the tariffs also underperform their roles of promoting efficiency and adequately reflecting the costs of the service provider, because tariff revenues are still insufficient to cover the operation and investment costs and to assure the financial sustainability of the water/wastewater utility. To these costs will be added, starting in 2008, the new water resources charge, associated with the recovery of scarcity and environmental costs, which will imply an additional effort to update the tariffs to more sustainable levels. The prevalence of increasing blocks and ad-hoc formulations in the calculation of the total amount to be paid hinders the comprehension of the true value of water without contributing to the objective of efficiency. The implementation of seasonal surcharges, which could be deemed as a more reasonable complication, from an economic point of view, is rare and does not coincide with the regions traditionally associated with the periodical scarcity of the resource.

One question which is usually mentioned as an obstacle to the implementation of efficient tariffs in water supply and sewerage is the financial capacity of households to pay the actual price of the service. For example, the Dublin Statement on Water and Sustainable Development states in its principle 4 that "it is vital to recognize first the basic right of all human beings to have access to clean water and sanitation at an affordable price" (ICWE (1992)). However, the same principle states that "Managing water as an economic good is an important way of achieving efficient and equitable use, and of encouraging conservation and protection of water resources" (ICWE (1992)). Roseta-Palma, Monteiro, Meireles, Mestre and Sugahara (2006) report that the water outlays of an average Portuguese family with the WS and WWDT services is less than 1% of the average household income. This should therefore not be a major obstacle to the reform of water tariffs in Portugal, although we should always consider the existence of specific poorer regions or the situation of households with lower incomes. In general, the incentive for the consumer to understand its water bill is small, given the low weight of the average water bill on the average income.

The distance between the actual tariffs and efficient pricing seems evident. In 2005, the last year covered by our analysis, half the time between the publication of the WFD and the 2010 deadline to implement efficient pricing had elapsed. We can say that by 2005, little seemed to have been done to adapt the Portuguese WS and WWDT tariffs to the new European legal requirements, which have already been transposed to the Portuguese Law by the new Water Law (AR (2005)) and the new Economic and Financial Regime for Water Resources (MAOTDR (2008*a*)). We hope that the future publication of the tariff regulation (MAOTDR (2008*b*)) and the current expansion of the powers of the Regulating Authority to all water/wastewater utilities may contribute to a change in the industry and a faster adaptation to the new legal framework.

Chapter 2

Evolution of Cost Recovery Levels in the Portuguese Water Supply and Wastewater Industry 1998-2005

2.1 Introduction

Cost recovery for water services is not a consensual recommendation across the world. While some international organizations from the developed world tend to recommend it as being essential for the financial sustainability of water utilities (OECD (2006); OECD (2009)), that is not the case for some worldwide reaching organizations such as the United Nations, which is more concerned with the impact such a principle would have on the poor, leading it to recognize the role that subsidization may have on the improvement of population provision levels in water supply and sewage drainage and treatment (UNDP (2006), WWAP (2006) and WWAP (2009)). This may be due to the fact that in developed countries, the water outlays represent a very small portion of the average household income, as we have seen for the Portuguese case in the end of chapter 2 (p. 47), whereas in developing countries the implementation of full cost recovery would put greater stress on households' budgets. Foster and Yepes (2006), for example report that in Latin America's "lower-income countries (Bolivia, Honduras, Nicaragua, and Paraguay), reaching cost recovery tariffs would represent a significant affordability problem for around half of the population" (ibid., p. 34). They compare these results to India and Africa where around 70% of households could be expected to face difficulties in paying full cost recovery tariffs[1]. Even when affordability is a real issue, the use of water consumption subsidies as a poverty alleviation measure can be controversial, not only because of their perverse effects on economic efficiency and the financial health of water utilities (Ruijs (2009)), but also because their efficacy is also questionable. For example, Komives, Wodon, Foster, Abdullah and Halpern (2006) find in their study that "most common forms of residential utility subsidies - quantity-based consumption subsidies such as increasing block tariffs - are highly regressive. Most poor households are excluded from these subsidies, and the majority of benefits accrue to the non-poor" (ibid., p. 3). Dahan and Nisan (2007) and Bithas (2008) provide further evidence on the unintended consequences of IBT pricing policies regarding the equity objective.

In theory, this is not an open debate for Europe, where, since the publication of the WFD in 2000, cost recovery in the water supply and sewage industry (including scarcity and environmental costs) has been a main focus of concern (despite the recent surge in interest in the notion of disproportionate costs from article 4 as a reason for exempting a region from compliance with WFD requirements). Although the document's main focus is the enhancement of the quality of Europe's water bodies, the introduction of specific sections dealing with economic and financial requirements and instruments has sparked a lot of debate, reports and action all over the European Union.

The WFD (EU (2000)) takes up the principle of cost recovery in water services in its article 9, requiring the economic analysis of water uses in article 5. WATECO (2003), Ribeiro, Serra and Cunha (2006) and Ribeiro (2007) provide an excellent overview of the economic implications of the WFD, its deadlines and the institutional settings in which it came about. For the purpose of our document it suffices to say that article 9 establishes 2010 as the deadline for the establishment of an adequate contribution of the several water users (at least households, agricultural and industrial users) for the implementation of cost

[1] For an example between these two extremes, see Fankhauser and Tepic (2005), a study of the impact by income group of implementing cost recovery prices in the energy and water industries in Eastern Europe and the countries which were once Soviet Republics.

recovery for the water industry. We assess the cost recovery situation in Portugal in 2005, halfway between the publication of the WFD and the meeting of the established deadline, considering the evolution since 1998. To our knowledge, this is the only independent assessment of cost recovery levels for the water industry outside the analysis performed by the Portuguese official institutions (Alves and Pinto (2004), INAG/MAOTDR (2005), INAG/MAOTDR (2007), INAG/MAOTDR (2008) and INAG/MAOTDR (2009)).

2.2 Cost recovery in Portuguese Law

In Portugal, the cost recovery principle has gained legal recognition, even though many times it still lacks practical implementation. This section describes the evolution of Portuguese Law regarding the cost recovery principle in the water industry, of which we present only a synthesis[2]. The remaining sections will assess its implementation.

The awareness about the need to raise revenues from the water supply activity to help finance infrastructure building can be found in Portuguese Law as early as 1892. The decree of 19 December 1892, regarding the hydraulic services of the Ministry of Public Works, defines in its article 21 the revenues of the water districts, assigning them to the public works to be performed in the district, including tariff payments for irrigation water, sand removal or license fees for the use of water surfaces to name a few (Ribeiro (2007), p.126).

According to Ribeiro (2007), p. 131, the requirement that the beneficiary should pay for public works improvement of water supply can also be found in the 1930's, where increased State intervention in the development of hydraulic works for agriculture is accompanied with the payment of an Irrigation and Improvement Charge (a fixed annual fee per hectare), which could be paid in money or in land. Regarding urban water supply, the Administrative Code of 1936 states in article 165 that water tariffs should be set "so as to cover the operation and management costs and to allow the formation of the necessary reserves" (ibid, p. 132). It was by this time also that water supply became one of the main

[2] More details on the history of the cost recovery principle in Portuguese legal documents are presented by Ribeiro (2007) and APDA (2006). See Unnerstall (2007) for a description of the introduction of the full cost recovery principle in the European environmental law and in the WFD.

tasks of the municipalities. Despite this evidence that revenue collection from users was important, this is far from pointing to full cost recovery. Just as an example, the investments in water and sewage infrastructure have always been subsidized by the State (and from 1986 onwards by European funds also). This is also pointed out by the Portuguese Association of Water Suppliers and Wastewater Drainage by stating that "the legal regime has always faced the difficulty intrinsic in the distance between the legal stipulations and their effective implementation. Examples can be found in the several attempts of the legislator to impose the economic balance of the services (...) also present, since the 40's, in the requirement that municipal services should have tariffs which covered the costs of operation and allowed the formation of the necessary reserves" (APDA (2006), p. 22).

Nevertheless, the principle that, at the very least, the service should not be free has been deeply entrenched in Portuguese legislation. The Decree-Law n. 70/90, which regulates the previous Framework Law for the Environment (approved in 1987 to update the Portuguese environmental law to the European Community standards, to which Portugal had just joined), also states that beneficiaries of water supply and sewage infrastructures should pay for their services. The several laws published since 1979 regulating the finances of the municipalities have always included water and sewage tariffs as part of the municipalities' revenues[3]. Furthermore, they established that the tariffs should cover operation and investment costs[4] (although this has not always been the case in practice as we shall demonstrate). This legal principle also covers the State-owned companies like EPAL[5] and

[3]The current version of the Law of Local Finances (for municipalities) is Law n. 2/2007 of January 15. Fees are established as legal revenue in article 16 whereas water and sewage tariffs/prices are established in article 17. Previous versions were: Law 1/79 of January 02; Decree-Law n. 98/84 of March 29; Law n. 1/87 of January 06; Law n. 42/98 of August 06.

[4]For example, article 9 of the Decree-Law n. 98/84 of March 29 stated that tariffs "should not be less than the forecasted operation and management expenditures plus the necessary amount for equipment amortization". This principle is still maintained in the current Law n. 2/2007, where article 16 n.1 reads "The prices and remaining payment instruments set by the municipalities regarding the services and goods supplied by the municipal organic units, either through direct management or through [autonomous] municipal services, should not be less than the cost directly or indirectly incurred with the activity of supplying those goods and services" (AR (2007)).

[5]EPAL is the water supplying company for the country's capital, Lisbon, and it also supplies bulk water to some neighbouring municipalities. APDA (2006), pp. 32-33, cites some examples regarding the presence of the cost recovery principle in the legislation regulating this company from 1974 onwards as it changed from a 100% State-owned public company to a Public Limited Company with share capital held by the State's holding company for the Water and Waste industry, AdP - Águas de Portugal.

the private concession services (which had been forbidden between 1977 and 1993).

The Economic and Financial Regime for the Water Resources published in 1994 (Decree-Law 47/94) introduced the polluter pays principle and the user pays principle in the Portuguese Law regarding the use of water resources (Ribeiro (2007), p. 138). It also includes the definition of charges for water withdrawals according to the water availability in the basin and wastewater effluent discharges into the environment according to the treatment cost for each pollutant type. The revenue raised in this way should have accrued to the budgets of the National Water Institute and the Regional Environmental Public Offices, but they were never implemented in practice for lack of subsequent regulation.

In 2005, a new Water Law was published transposing the WFD into Portuguese Law (AR (2005)). Its chapter VII brought with it a new economic and financial regime for water resources. The economic principles of the WFD are fully reflected in this law, which recognizes the economic value of water as a scarce resource and the principle of cost recovery for water services, including scarcity and environmental costs (ibid, articles 3 and 77). It also creates a water resources charge for the activities of water withdrawal, effluent discharge, sand removal and occupation of state-owned land or water surfaces. The revenues from the water resources charge must be used to promote water use efficiency, water resources quality and the improvement of water bodies and ecosystems and to finance the necessary infrastructures and administrative system. The water resources charge is a step forward in the internalization of scarcity-related opportunity costs and environmental costs. The implementation of cost recovery regarding the investment, operation and maintenance costs is left for the water tariff policy set by the water utility (ibid., article 82). Naturally, water tariffs must reflect the scarcity and environmental costs internalized by the water resource charge paid by the water utilities to the State[6]. Because cost recovery is surely impossible without the proper knowledge of the costs incurred, article 83 determines that it is the National Water Authority's task to perform economic analysis of water resource use at the river basin level.

Unlike the water resources charge set up in 1994, but which never saw the light of day

[6] Our analysis of cost recovery in this chapter is limited to its financial aspects as we do not consider scarcity and environmental costs.

due to the lack of subsequent legislation concerning its implementation, the new charge has already been in place since July 2008, after the publication of the Decree-Law 97/2008 of June 11, which establishes the new Economic and Financial Regime for Water Resources. The cost recovery principle (including scarcity and environmental costs) is assumed from the outset, within the spirit of the new Water Law and the WFD. Three instruments are established to meet the goals of sustainable water management through the promotion of water use efficiency, water conservation and water quality standards set up in the Water Law: the aforementioned water resources charge; water tariffs; contracted funding programs. The document not only determines the actual calculation procedure for the water resources charge, but also the division of the revenue generated between the National Water Institute, the recently created River Basin Authorities and a water resources protection fund to be created in a subsequent Decree-Law with the aim of promoting the rational use and protection of water resources. The articles concerning the water tariffs (chapter III, articles 20-23) set up the principles of cost recovery, financial sustainability of the water utility, water use efficiency and transparency in billing, but the details are referred to a later Decree-Law which will bring a new regime for water tariff setting, on which ERSAR has been working with the Ministry of Environment, Spatial Planning and Regional Development (MAOTDR (2008*b*)). Finally, the contracted funding programs' aim is to support investment in information and management technologies for water supply and pollution control, infrastructure building and the maintenance of water courses and adjacent shores (MAOTDR (2008*a*), article 25).

2.3 Methodology

The data on which we rely for this chapter was mainly provided by the Portuguese National Water Institute – INAG, which makes available on request its database from the National Inventory of Water Supply and Wastewater Systems (INSAAR). INSAAR periodically collects data on costs, revenues, investments, tariffs, volumes of water supplied and wastewater drained and management type. We have data for the years 1998, 2000, 2002 and 2005 (information on the type of management is for the last two years only, while the investment series has annual information starting in 1987). INSAAR is expected to be updated annually in the future.

Our work will only focus on mainland Portugal, for which reliable data was available at the time of our study[7]. However, there was still a significant amount of missing data, so we gathered additional information, namely on the volumes supplied and drained and the number of customers served, by directly requesting this information from the more than 300 Portuguese water and wastewater utilities.

Our analysis is made separately for WS systems and for WWDT systems, although the water utility providing them is often the same in each municipality. The analysis also separates retail and bulk water services, using the amount of water supplied/drained to allocate some of the costs faced by the water utility, when necessary.

The reference year for this study is 2005. This chapter updates results published for 2002 by Monteiro (2007). The main methodology followed there is maintained. Namely, the analysis of the evolution of the several indicators considers only those utilities with enough information for the period being analysed.

The calculation of annual investment costs involves the computation of the corresponding annuities from a deflated time-series of investments[8], using a 30 year maturity term and a 5% discount rate, which is the value recommended by the European Commission (EC (2008*b*), p. 14 and 33) for the discount rate to be used in cost-benefit analysis of long-term investment in infrastructures. This value is close to the 5,3% estimated by Evans and Sezer (2005) for the social discount rate in Portugal and similar to the 1987-2005 real profitability rates of long-term Portuguese Treasure bonds. Alves and Pinto (2004) also used a 5% discount rate for the economic part of the National Water Plan.

For reasons of statistical secrecy, regional analysis is performed at the NUTS III sub-regional administrative level.

[7] Mendes et al. (2006), p. 38, reports the later expansion of INSAAR to the Madeira and Azores archipelagos.

[8] The investment series from INSAAR does not include investments in the construction of dams.

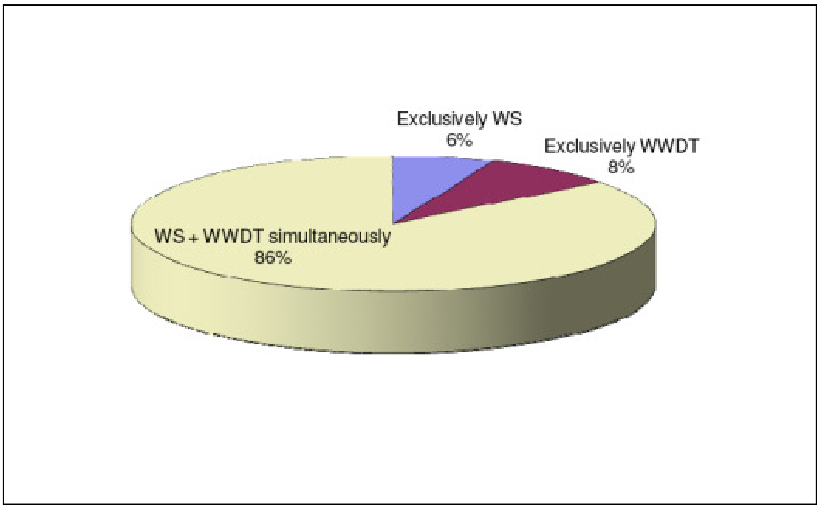
2.4 Brief description of water and wastewater utilities

The 2005 INSAAR update altered the number of utilities covered by the inventory from 610 (515 with WS services and 326 with WWDT services) to just 319 utilities (293 with WS and 299 with WWDT). The excluded utilities were of very small size, consisting of civil parishes (freguesias) or self-organized neighbourhoods, which seldom reported information anyway. All water utilities responsible for supplying water or draining and treating wastewater in each of the 278 municipal counties of mainland Portugal were kept, as well as all relevant bulk water and wastewater players. Nevertheless, this change makes the results from this study not strictly comparable with those from Monteiro (2007).

2.4.1 Nature of the service

Most Portuguese utilities present in INSAAR 2005 simultaneously provide WS and WWDT services (Figure 2.1). Only 6% were exclusively dedicated to WS and 8% dealt with WWDT only. As expected, 91% of these water utilities provide services directly to the consumer (households, industrial, commercial or agricultural businesses, public entities, among others), while the rest are focused on bulk water provision or wastewater drainage and treatment (6% doing it exclusively and 3% operating on both markets).

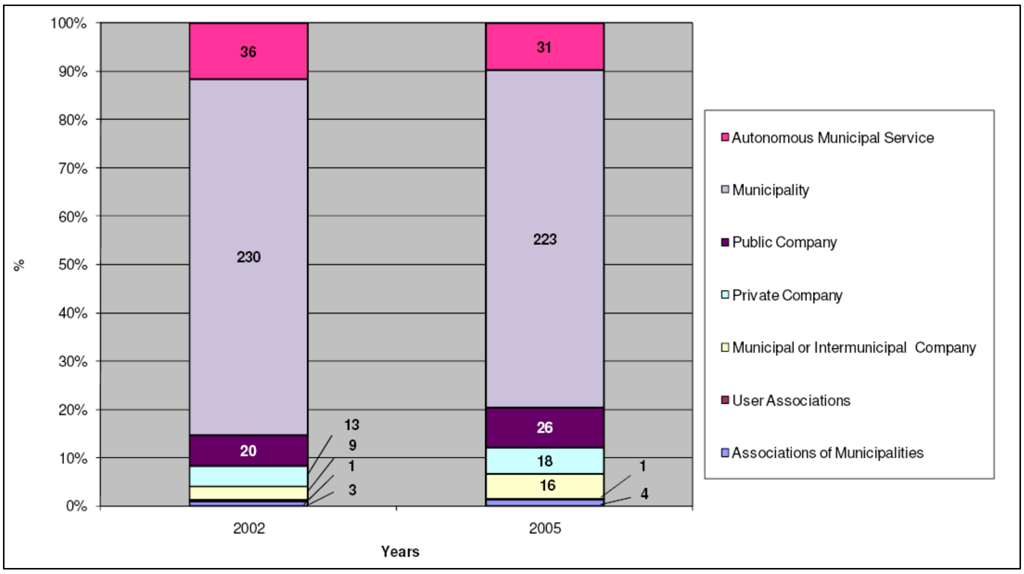
Figure 2.1: Classification of utilities by the nature of the service provided (2005)



2.4.2 Type of utility

Water utilities have been classified into 7 different types according to their ownership and management (Figure 2.2). In 2005, 70% of the Portuguese water utilities were municipalities, which have traditionally been providing the service in most cases. This figure is nevertheless down from 74% in 2002, reflecting the slow, but steady trend for municipalities to create autonomous entities to run the service or to concede it to private operators. This can be also seen from the increasing proportion of municipal companies (3% in 2002, 5% in 2005) and private companies (4% in 2002, 6% in 2005). The increasing number of public companies is mainly due to the creation of bulk water companies by the state-owned holding AdP, together with the municipalities involved.

Figure 2.2: Type of water utility/management (2002-05)



The different types of water utilities can be found in different locations across the country serving municipal counties with very different population sizes. In a careful analysis, one must, therefore, also look at their relative importance concerning the number of customers and the amount of water supplied/drained. The relative weight of municipalities for example, greatly diminishes in all kinds of services once such criteria are taken into account. They are responsible for WS and WWDT services all over the country, but it's in the smaller rural municipal counties that this type of management arrangement is almost universal. In larger, more urbanized municipal counties, the types of water utilities and management systems are more varied (Figure 2.3, Figure 2.4, Figure 2.5 and Figure 2.6).

Autonomous municipal services (which have an autonomous management within the municipality, although they are not an independent juridical entity), municipality-owned companies, private and public companies, on the other hand, have a greater importance in retail service if we look at other indicators besides the number of companies of each type, like the number of customer or the volumes supplied/drained. Although this reflects the growing importance of professional management in the industry, it hasn't yet implied a trend towards greater privatisation (private companies represented only for 4% of retail WS utilities and 3% in retail WWDT, serving 9% and 8% of customers, respectively).

In bulk WS and WWDT the situation is quite different. Public companies dominate the market. They are usually formed with a majority capital share from AdP, the state holding company, and a minority share from the municipalities they are intended to serve. In the ensuing cost analysis to be presented, average values are always weighted by the volume supplied/drained by each water utility.

Figure 2.3: Distribution of retail WS utilities by type (2005)

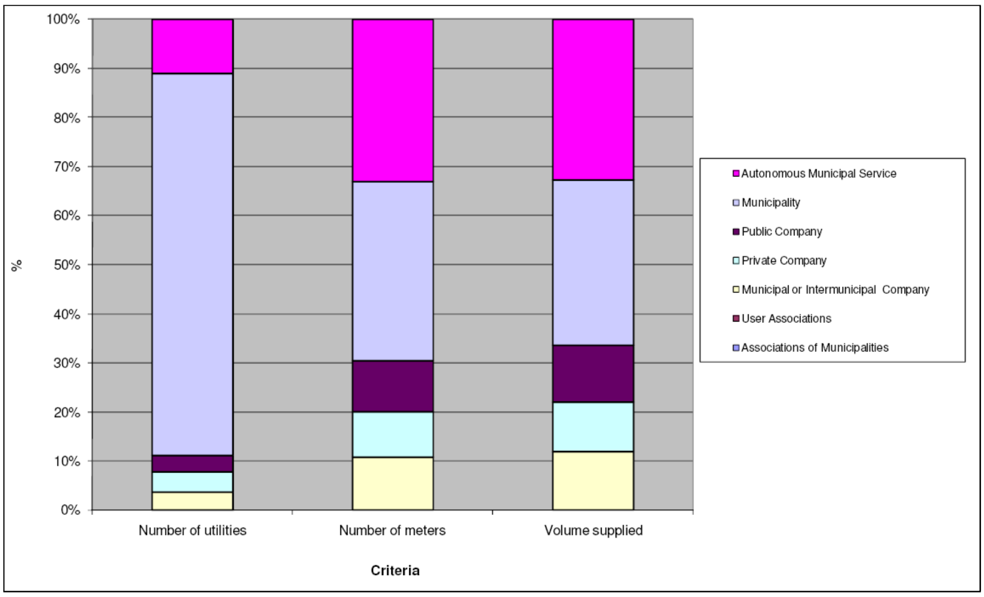


Figure 2.4: Distribution of bulk WS utilities by type (2005)

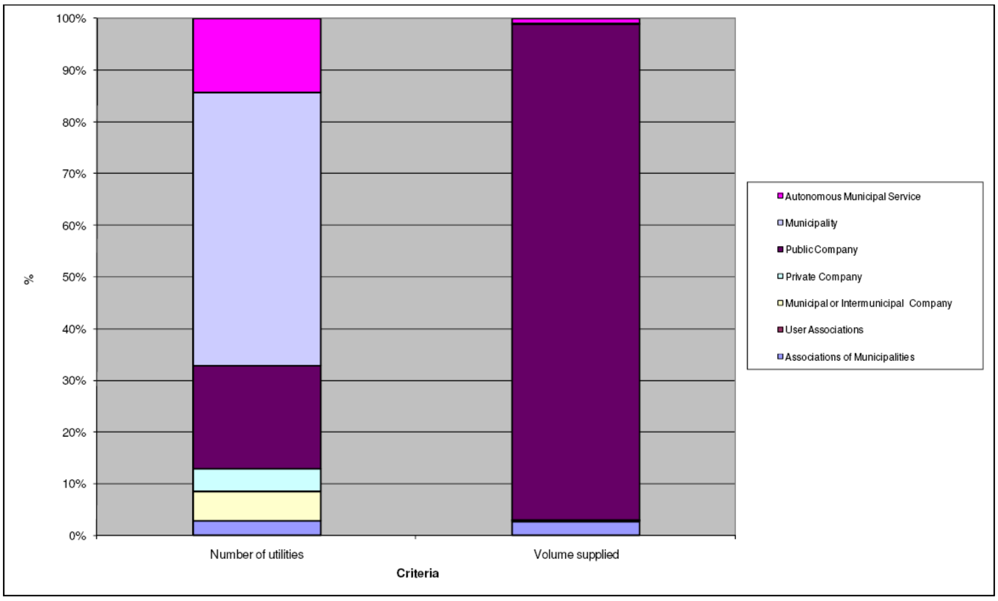


Figure 2.5: Distribution of retail WWDT utilities by type (2005)

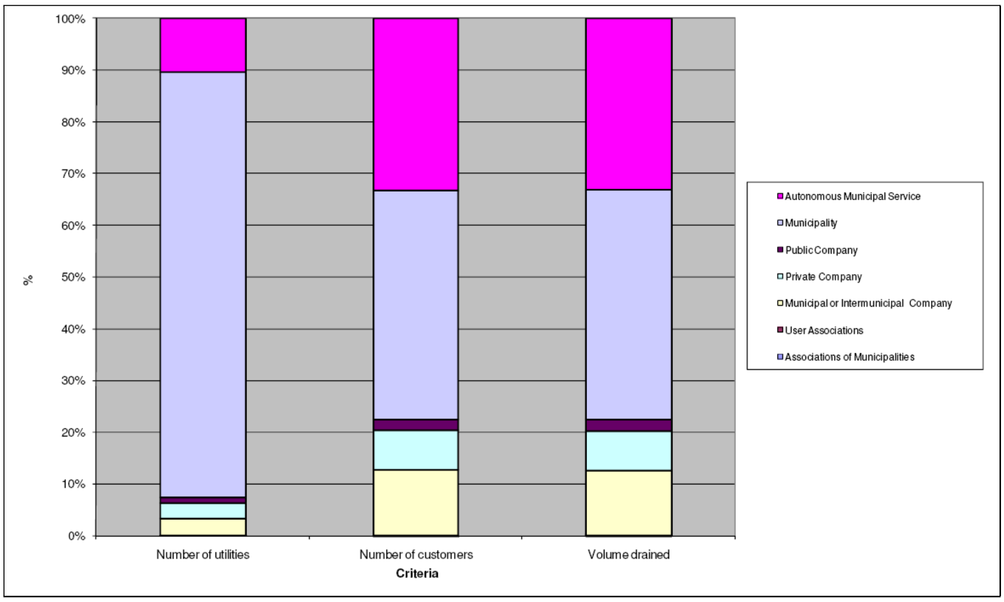
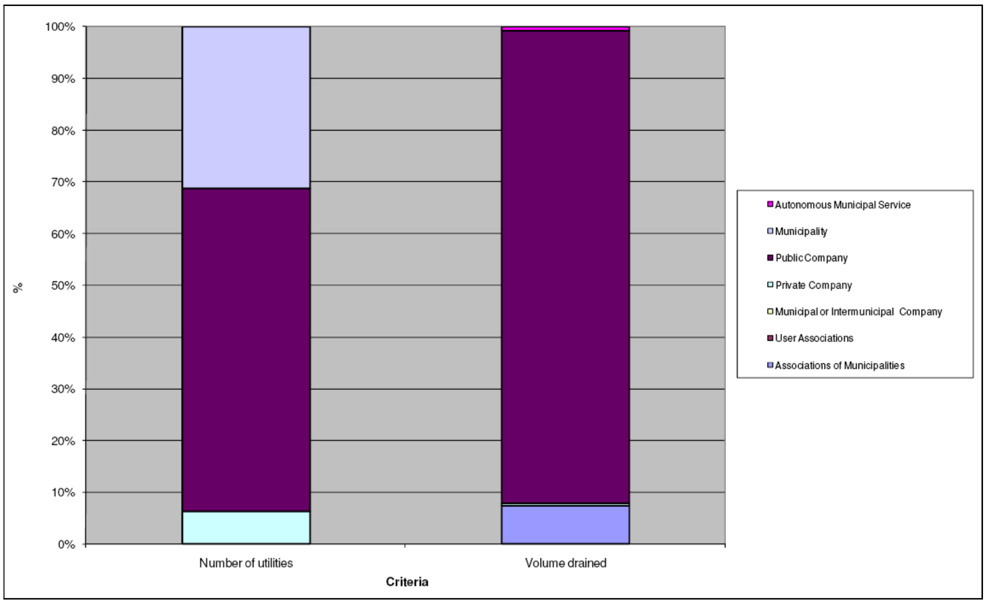


Figure 2.6: Distribution of bulk WWDT utilities by type (2005)



2.4.3 Geographical distribution

We now look at how the different types of retail water and wastewater utilities are located across Portugal. Figures 2.7 and 2.8 show that the great majority of the country is served by municipalities. It's in the more populous urban west coastline (or in some medium-sized inland cities, like district capitals, or in the Algarve, in the south) that we find alternative management arrangements. The traditional alternative was the autonomy of the municipal services within the municipality itself (without creating a distinct juridical entity) with the creation of specific management boards, usually separated from the city council members. In recent years, some municipalities, especially in the more densely populated cities have chosen to create municipal companies to run the services or even to concede it to private operators. This trend is visible in the maps below, even though they only show a 3 year difference. We also find some cases where the water utility is a state-controlled public company, but they have no regional pattern. We found no case of associations of municipalities operating at the retail level. This was expected, because these entities are created to deal with bulk water/wastewater. Recently, the government has been trying to create incentives (through the AdP holding and the management of contracted funding programs) for intermunicipal companies or associations to operate at the retail level, in order to seize economies of scale, but the impact of this policy will only be noticed in the future (Serra (2009)). It is important to note that some water systems are not confined to the municipal borders, so that Figures 2.7 and 2.8 always consider the predominant operator. Some water utilities supply two municipalities which have been divided after the system was created. Some systems may supply some population in adjacent counties. Finally, some inframunicipal operators exist, like tourist resorts, user associations, small neighbourhood organizations or civil parishes working under contracts for task decentralization with the municipality.

Figure 2.7: Geographical distribution of the main retail WS utilities in each municipal county (2002 and 2005)

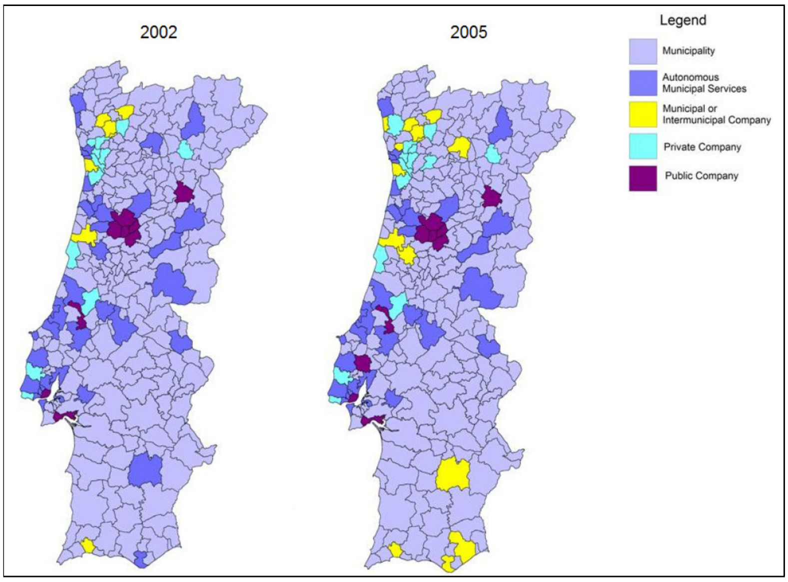
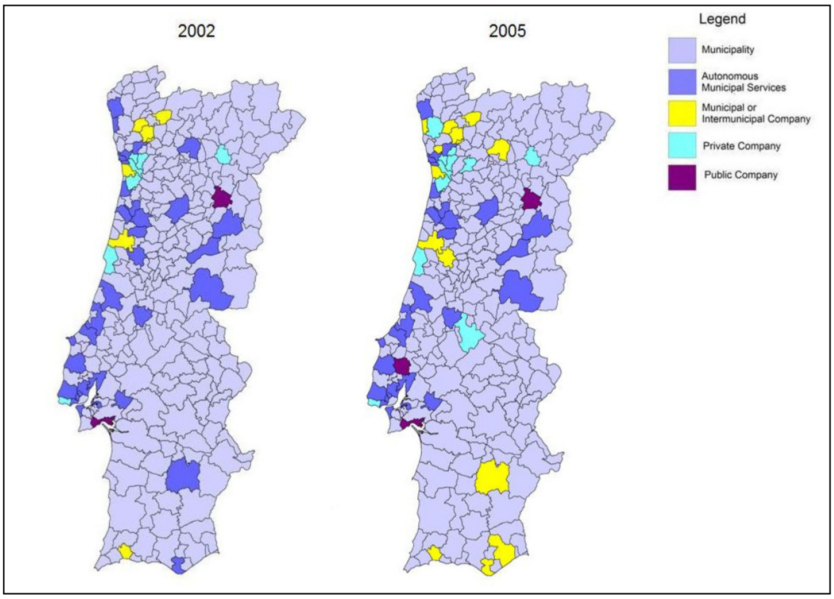


Figure 2.8: Geographical distribution of the main retail WWDT utilities in each municipal county (2002 and 2005)



2.5 Costs

In this section we look at the water utilities' cost amount and structure for WS and WWDT systems. Cost information comes from INSAAR 2005, as does the base information for the weights used (number of meters/customers and volumes supplied/drained). As noted earlier, additional information was gathered for the weight variables, in order to reduce the amount of missing data, through direct contacts with all retail water and wastewater utilities. We separate long-term investment costs from operation costs and also consider separately the costs of bulk water purchase/wastewater drainage, financial outlays and general administrative costs. The data is treated separately for WS and WWDT and for retail and bulk water activities[9]. Data is for the years 1998, 2000, 2002 and 2005 for all variables, excluding investments, which come from an annual time-series for the period 1987-2005. Where missing data might represent a problem, results are given considering only those utilities with enough information for the indicators at hand and for the relevant period being analysed and reporting the proportion of the volume supplied/drained they represent[10]. All monetary values use constant 2005 prices[11].

2.5.1 Total costs

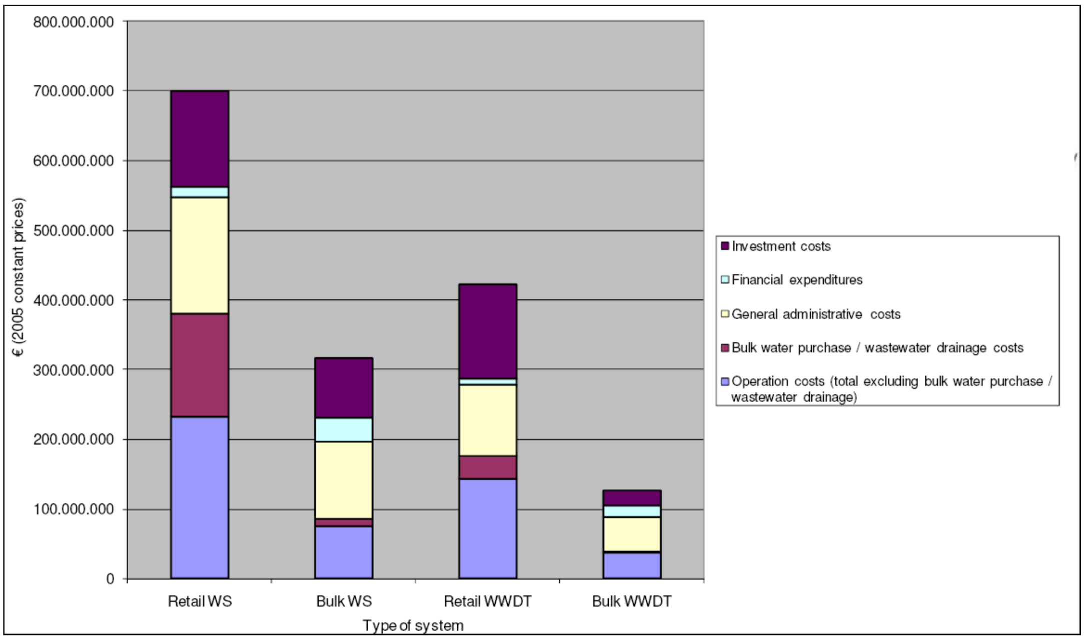
The costs of WS and WWDT systems in Portugal in 2005 amounted to 1566 million Euros. Figure 2.9 and Table 2.1 report the distribution of the different types of costs by the four types of systems (WS and WWDT, bulk and retail).

[9] Volumes supplied/drained are used as weights to allocate costs between bulk and retail activities when they are both present for the same utility.

[10] This procedure avoids, for example, the distortion that would be introduced by the fact that small utilities have lower data reporting levels for the first years under study. The missing data is much less of a problem in the data for customers and volumes than for costs and revenues.

[11] We used the deflator for Portuguese GDP at market prices, unit Euro/ECU, supplied by AMECO – Annual Macroeconomic Database of Directorate General for Economic and Financial Affairs (DG ECFIN) of the European Commission).

Figure 2.9: Total costs declared for WS and WWDT systems (2005)



The retail level was responsible for the large majority of the costs declared to INAG (72%) especially in WS (Table 2.1). WS represented 65% of the costs, while WWDT accounted for the remaining 35%. Two reasons may explain this difference: the delay in wastewater system expansion and the fact that not all water supplied is returned as wastewater to the sewage system (although in Portugal the lack of separate sewage systems for urban wastewater and rain water runoff means that it is possible that more water arrives at the wastewater treatment plant than the amount of water supplied).

Investment costs have a significant weight on the cost structure (24%), but the value is not as high as it could be expected (probably due to the fact that dam construction is excluded from the investment data) in an industry which is a flagship for the concept of natural monopoly, due to its capital-intensive nature. Nevertheless, if we add financial outlays like interest rate payments and general administrative costs (which can be considered for the most part as fixed costs), we reach the figure 57% of total costs. Operation costs account for the remaining costs, and it is noticeable that bulk water purchases represent 21% of all costs for retail WS, while wastewater drainage by bulk utilities represent only 8% of the costs of retail operators, reflecting the delay in the implementation of a bulk wastewater system in Portugal. In fact, bulk WS systems represented already 20% of the industry's costs (31% considering only WS), while bulk WWDT accounted for only 8% (23% considering only WWDT). This delay is also a feature of retail WWDT systems.

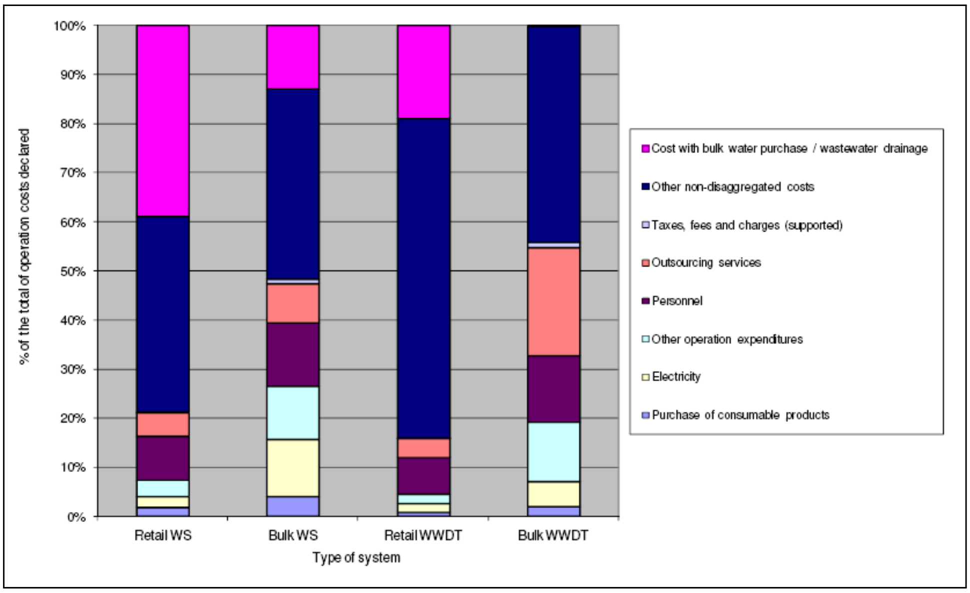
Table 2.1: WS and WWDT systems' costs (2005)

€10^3	Retail WS	Bulk WS	Retail WW	Bulk WW	Total
Operation costs (total excluding bulk water purchase / wastewater drainage)	232 645	75 202	142 840	38 971	489 658
Bulk water purchase / wastewater drainage costs	147 766	11 085	335 545	40	192 445
General administrative costs	166 820	109 738	102 021	49 478	428 057
Financial expenditures	14 946	35 565	9 204	16 256	75 971
Investment costs	138 277	85 192	134 442	22 244	380 155
Total	700 455	316 782	422 061	126 989	1 566 287
% of total by system type	Retail WS	Bulk WS	Retail WW	Bulk WW	Total
Operation costs (total excluding bulk water purchase / wastewater drainage)	33.2%	23.7%	33.8%	30.7%	31.3%
Bulk water purchase / wastewater drainage costs	21.1%	3.5%	8.0%	0.0%	12.3%
General administrative costs	23.8%	34.6%	24.2%	39.0%	27.3%
Financial expenditures	2.1%	11.2%	2.2%	12.8%	4.9%
Investment costs	19.7%	26.9%	31.9%	17.5%	24.3%
Total	100.0%	100.0%	100.0%	100.0%	100.0%
% of total by cost type	Retail WS	Bulk WS	Retail WW	Bulk WW	Total
Operation costs (total excluding bulk water purchase / wastewater drainage)	47.5%	15.4%	29.2%	8.0%	100.0%
Bulk water purchase / wastewater drainage costs	76.8%	5.8%	17.4%	0.0%	100.0%
General administrative costs	39.0%	25.6%	23.8%	11.6%	100.0%
Financial expenditures	19.7%	46.8%	12.1%	21.4%	100.0%
Investment costs	36.4%	22.4%	35.4%	5.9%	100.0%
Total	44.7%	20.2%	26.9%	8.1%	100.0%

2.5.2 Operation costs

The INSAAR 2005 data made available by INAG enables us to look into the structure of operation costs, although the proportion of those whose disaggregation was not reported by the water utilities is quite significant (Figure 2.10). Bulk water purchases represent a large proportion of operation costs for retail WS systems (39%). In retail WWDT, on the other hand, bulk operations still stand for only 19% of operation costs. The bulk systems' cost structure is somewhat different as this kind of expenditures are much less significant, with all other categories like outsourcing services, personnel or electricity having their weight on costs proportionally increased. It is interesting to notice that, even for bulk WS systems, the costs of buying water from other water utilities account for a non-negligible 13% of costs, which may be reflecting the impacts of local/regional water scarcity.

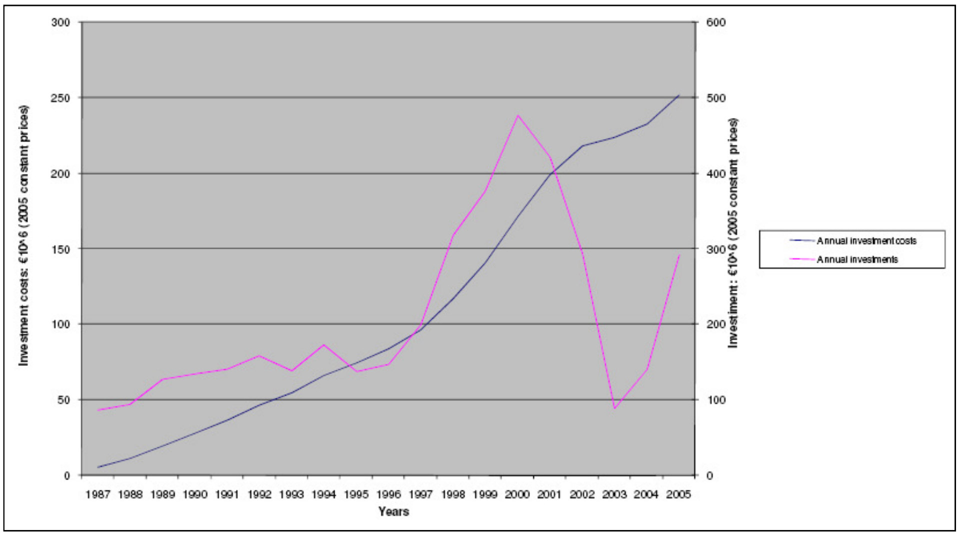
Figure 2.10: Distribution of operation costs reported in WS and WWDT (2005)



2.5.3 Investment costs

The investment time-series and their annual investment costs counterparts (obtained by calculating the corresponding annuities using a 30-year maturity term and a 5% discount rate) show a clear upward trend (Figure 2.11 and Figure 2.12). It is hard to point out the exact cause of the temporarily sharp decline in more recent years. It may be due to lack of reporting by the utilities for the years between surveys, but the fact that WS investment is already seen declining for 2002 (a survey year) may suggest that there may be a real cause (beyond the statistical one) for the decline in investment. It may be due to the transition between European structural funds support framework programmes. The 3^{rd} period of European fund support for Portugal terminated in 1999 and the subsequent one was meant for the period 2000-2006, so the decline in investment in the first years of a support framework programme may be something to be expected given the bureaucracy and delays usually associated with the setting up of the program and all the process of opening and deciding applications. In spite of all caution to be taken with these values, the upward trend matches the knowledge of increased public investment in the Portuguese water industry in recent years[12] spurred by large investment programs like PEAASAR 2000-2006[13].

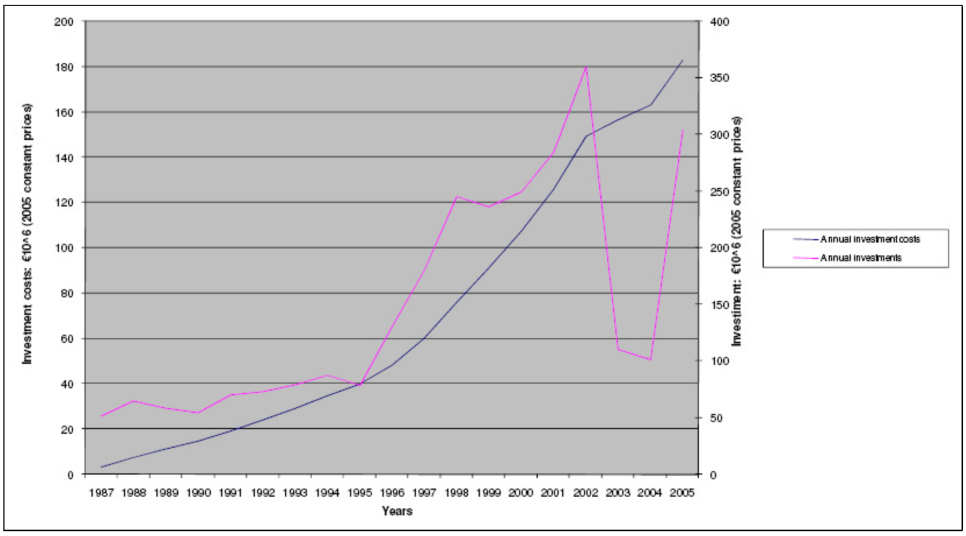
Figure 2.11: Evolution of investment costs in WS (1987-2005)



[12] The upward trend of the investment costs series is mathematically necessary given the 30-year maturity term considered and the less than 30-year length of the series.

[13] PEAASAR - Plano Estratégico de Abastecimento de Água e Saneamento de Águas Residuais [Strategic Plan for Water Supply and Wastewater Sewage] is a government backed plan to support infrastructure building by the industry, within the overall Community Support Framework seizing European structural funds for the period. A new plan (PEAASAR II) has already been designed and is being implemented for the period 2007-2013 (MAOTDR (2007*a*)).

Figure 2.12: Evolution of investment costs in WWDT (1987-2005)



The distribution of investment between WS and WWDT systems has changed significantly since 1987. In 1987, WS systems received 63% of the investment in the industry, while in 2005 the situation was more balanced with WWDT already comprising 51%. The proportion of the corresponding investment costs in WWDT increased from 38% to 42% during the period.

2.5.4 Costs per utility and unit costs

We now turn our attention to the cost per utility and the unit costs[14] in WS and WWDT systems. We will look into the costs per customer and per cubic meter of water supplied/wastewater drained.

We can see from Figure 2.13 that, as expected, bulk operators face rather larger costs than retail utilities, with €7.5 million on average for WS and €5 million for WWDT. Wastewater systems face an average total annual cost which is about 2/3 of the corresponding water supply system.

[14] The concept of unit cost used here is equivalent to the economic concept of average cost. We calculate average (unit) costs per customer and per m^3. We do not calculate marginal costs.

Figure 2.13: Average cost per utility in WS and WWDT systems (2005)

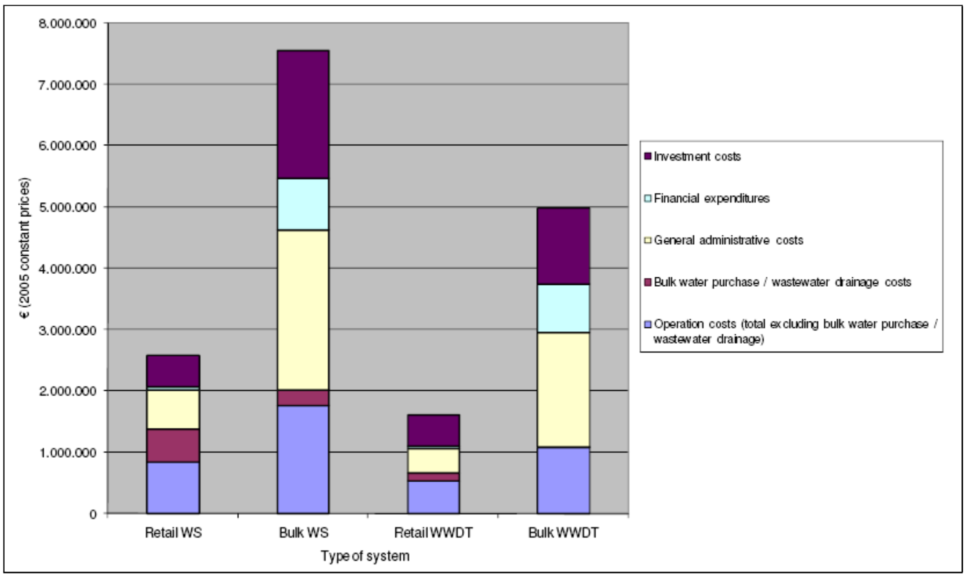
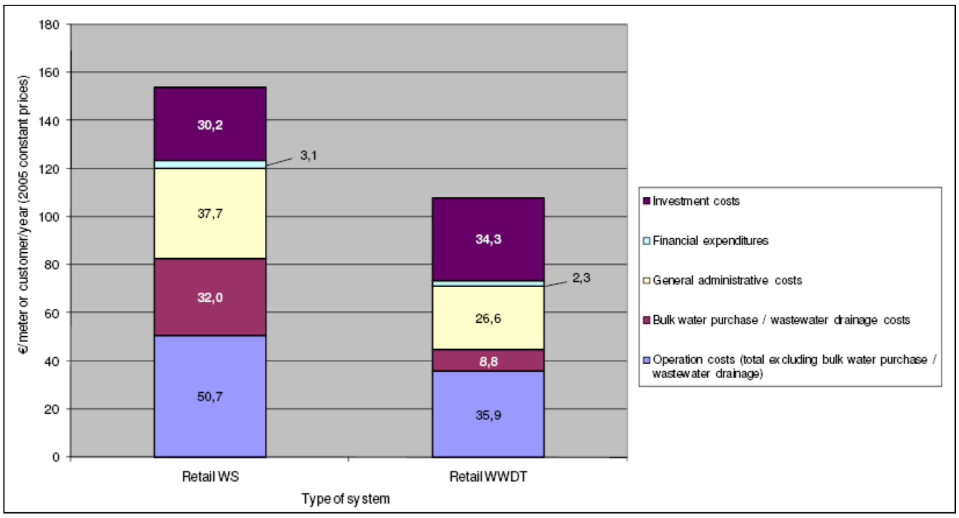


Figure 2.14 shows that the cost of providing the retail WS and WWDT service to a customer is on average €261.6/year (€153.7/year for WS and €107.9/year in WWDT). The difference is probably due to the fact that the population coverage is still insufficient in WW drainage and even lower in WW treatment. According to INAG/MAOTDR (2009), p. 55, 79 and 84, while 92% of the population was served by WS in 2006, only 80% had a wastewater drainage system and only 70% were served by wastewater treatment plants.

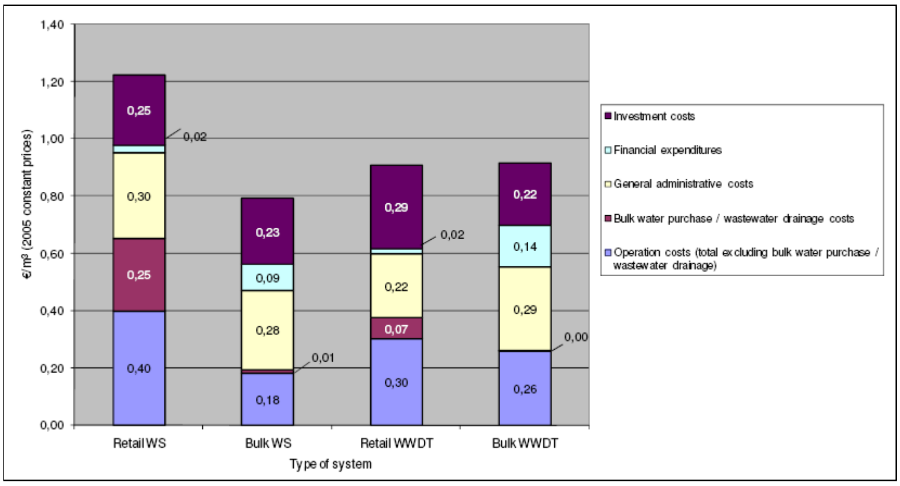
Figure 2.14: Annual unit cost per customer in retail WS and WWDT systems (2005)



In 2005, in Portugal, supplying 1 m^3 of drinking water had an average cost of €1.22 (Figure 2.15), while the drainage and treatment of 1 m^3 of wastewater cost €0.91. For WS, the cost for bulk water is significantly lower (€0.79/ m^3), which is something to be expected, given the economies of scale that a larger water utility can take advantage of while supplying water to a number of retail operators. Bulk water providers are also expected to maintain a smaller network length, not having to reach every single final customer. Retail operators, on the other hand, buy bulk water and have additional distribution costs on top of that. The situation is more balanced for WWDT where draining and treating 1 m^3 of bulk wastewater costs nearly the same (€0.92/ m^3) as for retail wastewater. This may be a statistical effect of averaging those retail operators that still have insufficient coverage and treatment levels with the ones which are more advanced in completing the system. As required treatment levels are upgraded for all WWDT utilities we can expect the unit cost of retail WWDT to increase.

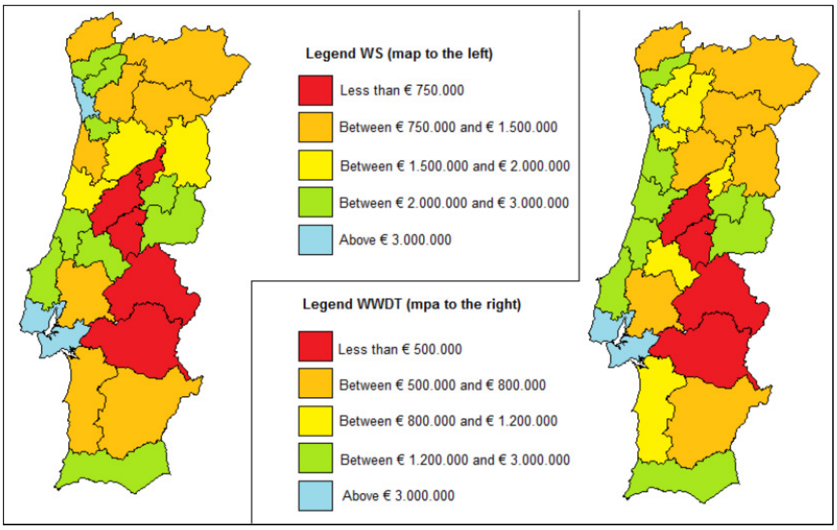
The 2006 Annual Report on Water and Waste Industry in Portugal (RASARP) cites "international research, according to which the average service providing cost for 1 m^3 of water is around €1, the cost of sewage for 1 m^3 of wastewater being significantly higher" (IRAR (2007), vol.1, p. 32). Our results are similar, only differing in the fact that it is the WS cost which is found to be higher. The higher unit cost for WS may be due to the small size of WS systems in Portugal, something that the government has been trying to change in recent years.

Figure 2.15: Average unit cost per m^3 in WS and WWDT systems (2005)



We can look now at the geographical distribution of unit costs at NUTS III level. The regional distribution of costs per utility follows closely the distribution of the population as expected. The water/wastewater utilities facing the greatest costs are located mainly in the west and south coasts, especially around the two metropolitan areas of Lisbon and Oporto (Figure 2.16).

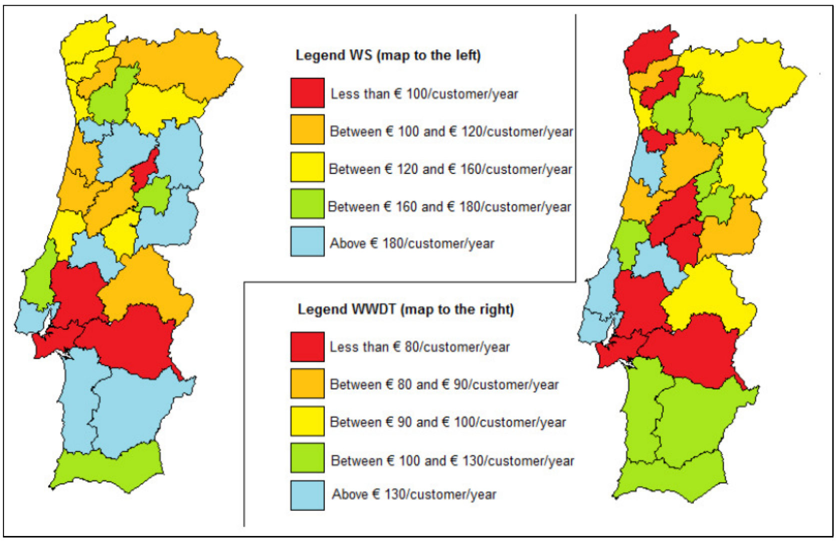
Figure 2.16: Average cost per utility in retail WS and WWDT by NUTS III (2005)



Analysing unit costs per customer can be more complex, because lower unit costs can be due to greater efficiency in the service or to the existence of scale economies, but can also be a product of a lower investment in the quality of the service provided, for example in the treatment of drinking water or wastewater before being released into the environment[15]. Figure 2.17 shows no evident regional pattern.

[15]ERSAR's (ex-IRAR) annual reports (IRAR (2007)) provide detailed information on water quality (for all WS utilities) and water service quality (for concessions). Our suspicion seems to be confirmed by the statement that "Utilities' performance, regarding sampling frequency failures and mandatory quality parameters failures, still reflects the Portuguese regional development inequalities. Indeed, it's in the inland regions, with greater lack of human, technical and financial resources, that failures to comply are concentrated, something that hapens mainly in supply zones with less than 5000 inhabitants" (ibid., vol. 4, p. viii). APDA (2006) also reports data on sampling frequency failures and mandatory quality parameters failures.

Figure 2.17: Average unit cost per customer in retail WS and WWDT by NUTS III (2005)



The same can be said about Figure 2.18, regarding the possible confusion between efficiency and low service quality as reasons for lower costs. Nevertheless, a patter can be found, because unit cost per m^3 seems to be higher in the northeast inland part of the country, probably due to the more rugged terrain that can be found in that region or the more diffuse nature of population settlings. Those are hardly the reasons to explain the fact that unit costs are also high in south Alentejo, a plain land with low population density, but with population being concentrated in few villages and cities.

Figure 2.18: Average unit cost per m^3 in retail WS and WWDT by NUTS III (2005)

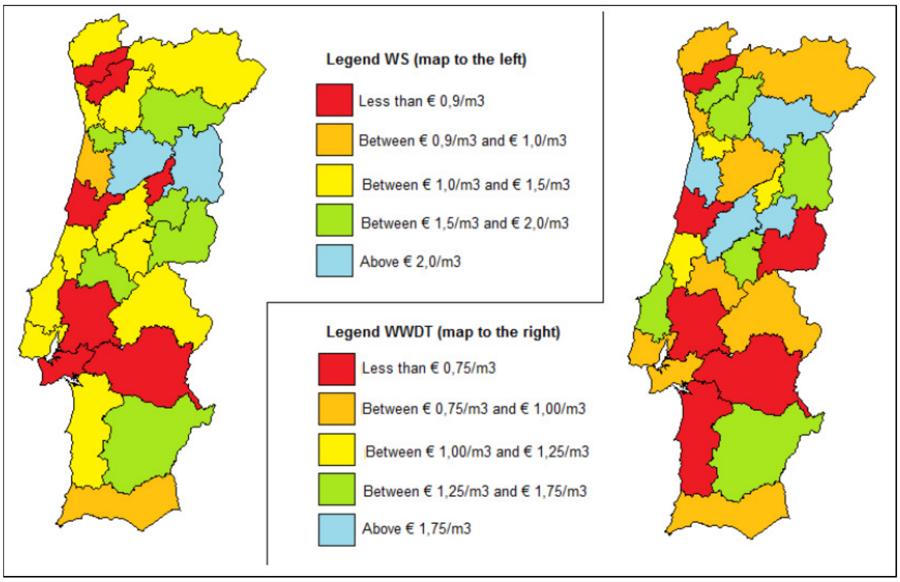


Figure 2.19 shows the regional distribution of the population density (map to the left) and the difference between the maximum and the minimum altitude (map to the right) in each region. It shows that the greater population density in the west coast of Portugal and the plainer landscape in the west and in the south could be reasons for lower unit costs in these regions.

Figure 2.19: Population density and altitude variation by NUTS III (2005)

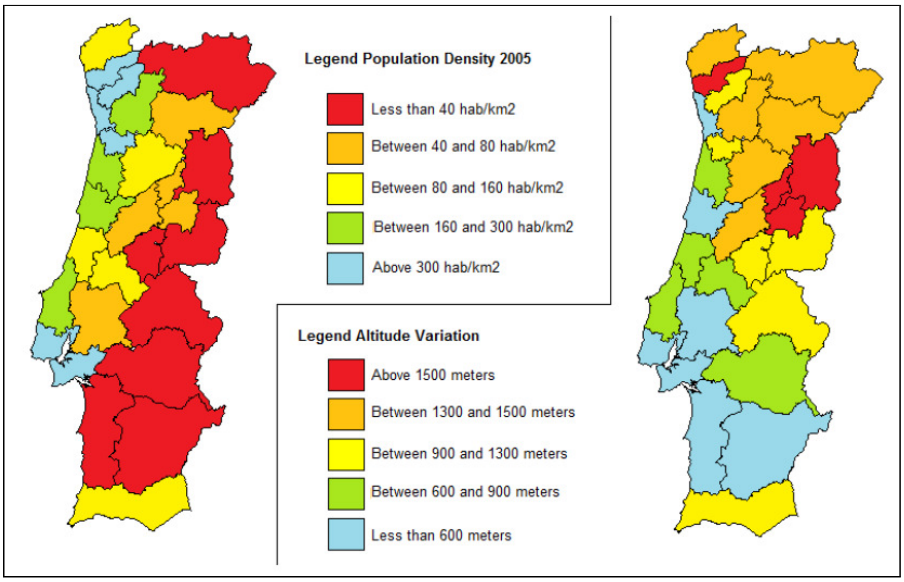
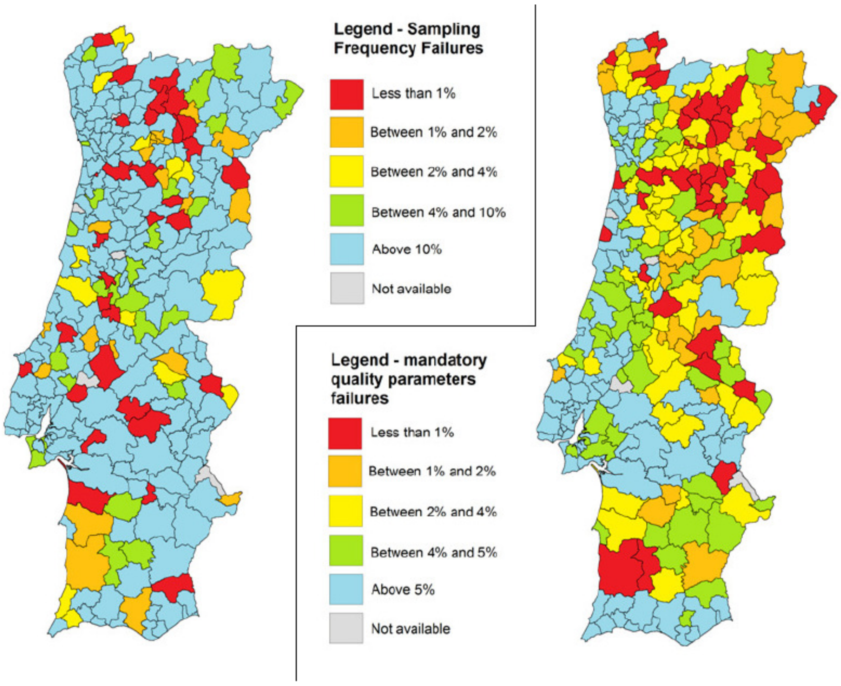


Figure 2.20, on the other hand, presents data from ERSAR (ex-IRAR) on water quality indicators and shows that they are lower in the northern inland part of the country (and in the south of Alentejo), which could result from lower investments in water quality in these regions. These two conflicting trends may explain the mixed results in Figure 2.17 and Figure 2.18.

Figure 2.20: Water quality indicators: sampling frequency failures and mandatory quality parameters failures by municipality (2005)



We now take a look at the distribution of unit cost by type of utility/management (Table 2.2). Municipalities are the type of water utilities with fewer costs on average because they are responsible for providing the services of WS and WWDT all over the country, not just in the big cities. They are the predominant type of utility in less densely populated and less urbanized regions. The other types of utilities, which are more commonly found in urban areas are several times larger and therefore face higher total costs.

Municipalities and municipal companies have the lowest unit costs per customer (together with the autonomous municipal services in WWDT), which is something that we would not be expecting if we considered only the possible economies of scale[16]. However, autonomous municipal services show high unit costs. This prevents us from making any fi-

[16] We do not rigorously assess in this chapter if there are economies of scale or not, nor do we try to estimate an optimal size for the water/wastewater utilities. That kind of analysis for Portugal was done by Martins, Coelho and Fortunato (2008), who conclude "the industry seems to exhibit economies of scale. There are, therefore, pro-aggregation arguments, especially for small and medium sized local water supply systems" (ibid., p. 23). Chapter 6 presents our own estimation and some conflicting results.

nal judgement on the issue of whether a transition towards more professional management and more privatisation of services leads to higher costs or not (and to a correspondingly higher service quality).

Table 2.2: Unit cost by type of utility in retail WS and WWDT (2005)

	Average cost per utility (2005) (€)		Average unit cost per customer (2005) (€/customer/year)		Average unit cost per m^3 (2005) (€/m^3)	
	Retail WS	Retail WWDT	Retail WS	Retail WWDT	Retail WS	Retail WWDT
Municipality	960 250	853 225	115. 0	105. 2	1. 03	0. 92
Autonomous Municipal. Services	9 262 797	6 015 463	180. 9	105. 6	1. 46	0. 98
Municipal or Intermunicipal Company	4 999 084	3 768 359	141. 8	106. 9	0. 86	0. 74
Public Company	9 156 634	3 310 183	158. 5	137. 4	1. 10	0. 66
Private Company	7 526 761	4 628 116	237. 5	121. 6	1. 68	0. 89
Total	2 575 230	1 611 120	153.7	107.9	1.22	0.91

2.5.5 Rates of change in costs

The INSAAR data on costs and revenues is somewhat affected by a non-negligible amount of missing data which requires the calculation of rates of change to be made and interpreted with some caution. For the case of cost totals one must take into account the fact that some years may be lacking more information than others, so that simple rates of change would reflect the entrance and departure of utilities from the database at least as much as the actual change in costs. To prevent this effect we calculate the rates of changes between any two years considering only those utilities which reported data for the two years at hand for the cost category being analysed. The results are qualitatively similar to those obtained if we considered only the utilities which had information for all 4 years, but the amount of utilities/information discarded is much less.

Table 2.3 [17] presents the results. The overall main result that stands out is the signif-

[17] The following cost categories have a significant amount of missing data: Bulk water purchase / wastewater drainage costs; General administrative costs; Financial expenditures. For tables 2.3, 2.4 and 2.5 we only considered the information explicitly reported by the water/wastewater utilities (we only considered those which had information on costs for the two years under consideration, the % of volume supplied/drained in the latter year by the utilities being considered is shown in parenthesis). To keep missing data from preventing the calculation of cost recovery ratios, the rest of the document will follow

icant real cost increases in all types of systems throughout the period (in 2005 constant prices), reflecting the expansion of the systems that occurred. This can also be seen by the increase in investment costs[18] and financial expenditures (subsidies only support part of the investment). In general, the expansion of the bulk water/wastewater systems is already being reflected in the increase in cost with water purchases/wastewater drainage for retail operators. With few exceptions, the several cost categories show very significant real growth.

the assumption that missing data is due to a lack of reporting of null values for these three cost categories and will interpret them as such. We do not follow this procedure here because this would overestimate growth rates for these specific categories of costs. The same procedures are followed in the section for revenues.

[18] It is possible that the investment costs' growth rates are somewhat overestimated due to the fact that the length of the time series is inferior to the maturity term considered in the calculation of the corresponding annuities.

Table 2.3: Average annual rate of change in costs in WS and WWDT (1998-2005)

Type of system	Type of costs by system	Average annual rate of change		
		98-00	00-02	02-05
Retail WS	Operation costs (total excluding bulk water purchase)	4.5% (41%)	1.8% (49%)	-2.2% (92%)
	Bulk water purchase costs	6.5% (48%)	7.9% (67%)	9.1% (46%)
	General administrative costs	6.5% (89%)	79.5% (92%)	13.1% (92%)
	Financial expenditures	21.0% (27%)	-4.9% (29%)	43.7% (88%)
	Investment costs	11.4% (94%)	10.3% (97%)	0.9% (98%)
	Total costs	11.7% (40%)	12.7% (48%)	3.4% (91%)
Bulk WS	Operation costs (total excluding bulk water purchase)	82.5% (14%)	5.1% (56%)	-4.4% (93%)
	Bulk water purchase costs	12.9% (89%)	15.3% (96%)	-8.6% (15%)
	General administrative costs	52.5% (86%)	290% (94%)	13.5% (95%)
	Financial expenditures	-19.4% (8%)	1.3% (49%)	50.7% (97%)
	Investment costs	35.7% (87%)	15.8% (95%)	0.8% (95%)
	Total costs	61.1% (12%)	13.2% (54%)	5.3% (91%)
Retail WW	Operation costs (total excluding drainage)	16.5% (46%)	11.8% (55%)	-7.1% (92%)
	Wastewater drainage costs	23.6% (11%)	7.8% (11%)	3.0% (21%)
	General administrative costs	37.5% (88%)	67.8% (88%)	14.5% (92%)
	Financial expenditures	2.4% (23%)	58.8% (26%)	109.5% (78%)
	Investment costs	19.9% (88%)	15.7% (89%)	2.1% (98%)
	Total costs	19.9% (43%)	27.4% (50%)	1.6% (91%)
Bulk WW	Operation costs (total excluding drainage)	-1.6% (84%)	-15.4% (60%)	-2.4% (70%)
	Wastewater drainage costs	-	-	-
	General administrative costs	27.7% (99%)	6.2% (66%)	40.2% (70%)
	Financial expenditures	-	-	121.1% (70%)
	Investment costs	11.8% (99%)	11.6% (66%)	-1.5% (70%)
	Total costs	0.3% (84%)	0.2% (60%)	12.0% (70%)

Tables 2.4 and 2.5 show a significant real increase in unit costs throughout the period (with occasional exceptions for WWDT in specific years). This happened in spite of some economies in unit operational costs, especially in more recent years. Investment costs have increased in the beginning of the period, but show a slight decrease in 2002-05 due to the decline in investment in those years (which picked up in 2005). General administrative costs seem to have suffered a widespread increase for all operators. It is also noticeable that the costs with bulk water purchases/wastewater drainage show a steady growth. The representativeness of the results may vary according to the missing data in the database. Overall, the utilities used in the calculation represent a very satisfactory proportion of the market in terms of volumes supplied/drained, but because this may not happen in some specific cost categories in specific years, we show the representativeness of the results (% of volume supplied/drained in the latter year by the utilities being considered) in parenthesis in the tables.

Table 2.4: Average annual rate of change in per customer unit costs in WS and WWDT (1998-2005)

Type of system	Type of costs by system	Average annual rate of change		
		98-00	00-02	02-05
Retail WS	Operation costs (total excluding bulk water purchase)	0.4% (41%)	-1.8% (49%)	-4.7% (92%)
	Bulk water purchase costs	3.3% (48%)	4.6% (67%)	6.3% (46%)
	General administrative costs	2.7% (89%)	73.9% (92%)	10.2% (92%)
	Financial expenditures	16.6% (27%)	-8.2% (29%)	39.9% (88%)
	Investment costs	7.4% (94%)	6.8% (97%)	-1.7% (98%)
	Total costs	7.2% (40%)	8.8% (48%)	0.7% (91%)
Retail WW	Operation costs (total excluding drainage)	11.7% (46%)	7.3% (55%)	-9.7% (92%)
	Wastewater drainage costs	20.7% (11%)	5.0% (11%)	1.3% (21%)
	General administrative costs	32.1% (87%)	60.9% (87%)	11.6% (91%)
	Financial expenditures	-1.3% (22%)	53.3% (26%)	117.0% (77%)
	Investment costs	15.3% (87%)	11.9% (88%)	-0.7% (97%)
	Total costs	15.1% (42%)	22.4% (49%)	-1.1% (91%)

Table 2.5: Average annual rate of change in per m3 unit costs in WS and WWDT (1998-2005)

Type of system	Type of costs by system	Average annual rate of change		
		98-00	00-02	02-05
Retail WS	Operation costs (total excluding bulk water purchase)	0.6% (41%)	-0.9% (49%)	-3.4% (92%)
	Bulk water purchase costs	3.2% (48%)	6.0% (67%)	7.2% (46%)
	General administrative costs	1.4% (89%)	76.0% (92%)	11.7% (92%)
	Financial expenditures	16.6% (27%)	-8.1% (29%)	41.9% (88%)
	Investment costs	6.1% (94%)	8.0% (96%)	-0.4% (97%)
	Total costs	7.5% (40%)	9.8% (48%)	2.1% (91%)
Bulk WS	Operation costs (total excluding bulk water purchase)	42.7% (14%)	-5.7% (56%)	-3.6% (93%)
	Bulk water purchase costs	-10.8% (89%)	4.9% (96%)	-10.0% (15%)
	General administrative costs	19.3% (86%)	258% (93%)	14.2% (91%)
	Financial expenditures	-26.8% (8%)	-8.2% (49%)	50.7% (92%)
	Investment costs	6.7% (86%)	6.6% (94%)	2.1% (91%)
	Total costs	21.5% (12%)	0.8% (54%)	7.1% (91%)
Retail WW	Operation costs (total excluding drainage)	6.8% (46%)	7.1% (55%)	-10.9% (92%)
	Wastewater drainage costs	12.0% (11%)	7.4% (11%)	2.0% (21%)
	General administrative costs	24.8% (88%)	60.7% (88%)	10.1% (92%)
	Financial expenditures	-3.9% (23%)	47.9% (26%)	99.1% (78%)
	Investment costs	8.9% (88%)	10.7% (89%)	-1.4% (98%)
	Total costs	9.6% (43%)	22.7% (50%)	-2.9% (91%)
Bulk WW	Operation costs (total excluding drainage)	-4.5% (84%)	-8.5% (64%)	-10.0% (70%)
	Wastewater drainage costs	-	-	-
	General administrative costs	4.0% (84%)	10.7% (64%)	33.5% (70%)
	Financial expenditures	-	-	92.1% (62%)
	Investment costs	-1.0% (84%)	16.1% (64%)	-4.8% (69%)
	Total costs	-2.7% (84%)	8.4% (60%)	9.0% (69%)

Even though the unit costs are seen to be raising above the inflation rate (probably due to more stringent quality requirements and new investments) the growth rates for unit costs are more moderate than the ones for total costs as can be seen if we compare Table 2.3 with Table 2.4 and 2.5. This reflects some possible economies of scale being seized as the systems expand their coverage and provide higher volumes.

2.6 Revenues

In this section we analyse the revenues of Portuguese water and wastewater industry, from the data reported to INSAAR for the period 1998-2005. We will use the same division of the systems into bulk and retail and WS and WWDT. Revenues will be divided into non-tariff and tariff revenues from services provided to the final customers or from transactions between water/wastewater utilities. Investment subsidies will also be taken into account[19]. Non-tariff revenues (excluding investment subsidies) are exclusive features of retail water operators in the INSAAR database. Unlike the situation for the cost analysis, here all revenues have a clear association with one of the 4 types of systems considered, so that no weighting criterion was needed to distribute them between retail and bulk systems in the cases where the same utility has activity in both.

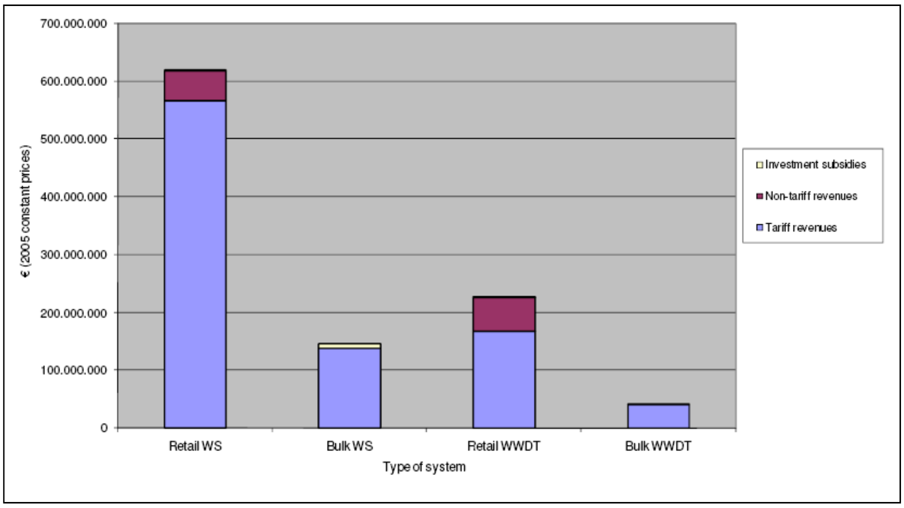
2.6.1 Total revenues

The revenues in the WS and WWDT industry in 2005 amounted to €1035 million (Figure 2.21), a figure well below the one reported for the total costs (Figure 2.9) as we will see in the section for cost recovery ratios. For now, we will look more carefully into the revenue structure of the industry, which according to INSAAR is mainly comprised of tariff revenues. The weight of non-tariff revenues and investment subsidies in the revenue totals is rather small, although we do suspect that investment subsidies are very understated in

[19] Although the INSAAR database does include investment subsidies and we do consider them as revenues in our analysis, the amounts reported to INSAAR by the water utilities are virtually negligible and do seem to be very far away from the actual level. Investment subsidies are treated here as revenues in the same fashion as investment costs, i.e., they are calculated annuities from the actual investment subsidies time-series using a 30-year maturity term and a 5% discount rate.

the database due to lack of reporting[20].

Figure 2.21: Revenues in WS and WWDT systems (2005)



The great majority of the revenues are raised in the WS systems, which account for 74% of all revenues. Retail WS receives 60% of revenues and bulk WS the remaining 14%. On the other hand, WWDT systems receive only 26% of all revenues, 22% in the retail activities and 4% in bulk wastewater. WWDT systems receive 27% of the retail revenues and 23% of the bulk water/wastewater revenues. These are lower proportions for WWDT than we found for the costs, especially in retail activities, which is a first evidence of the existence of cross-subsidization between both activities.

Focusing on the division between retail and bulk water/wastewater activities, we see that the latter account for less than 1/5 of the revenues (18%). The proportion is smaller

[20] For example, the total amount of subsidies reported to INSAAR (at current prices) for the period 2000-2005 is around €250 million, while Roseta-Palma et al. (2006) report that € 506.7 million were planned in the Cohesion Fund alone to be applied in the industry's investments between 2000 and 2006 (ibid., p. 17, table 3). To this value we must add the €621.8 million from the European Regional Development Fund to get a total of €1128.5 million of planned European funds to be applied as investment subsidies in the industry in this period (Portuguese governmental funds would had to these values). We must note that, for the Cohesion Fund, by 2004, although €405.4 million of funding had already been approved, only €86 million had been executed. Nevertheless, if we take into account the fact that the amount of investments reported to INSAAR for the period 2000-2005 reaches €3113 million (current prices) and that the share of European funding on supported investments reached 67% on average (IRAR (2007), vol. 1, p. 88, table 14), we must take some caution with the data on subsidies reported to INSAAR.

for WWDT, whose bulk activities represent 16% of the total WWDT revenues while the figure for bulk WS is 19%.

2.6.2 Tariff revenues

The fixed component of the tariff has a very significant weight on the tariff revenues, especially for WWDT (Figure 2.22), due to the importance of investment costs for the industry (Table 2.1 showed that investment costs amount to between 18% and 32% of all costs, according to which system we are looking at).

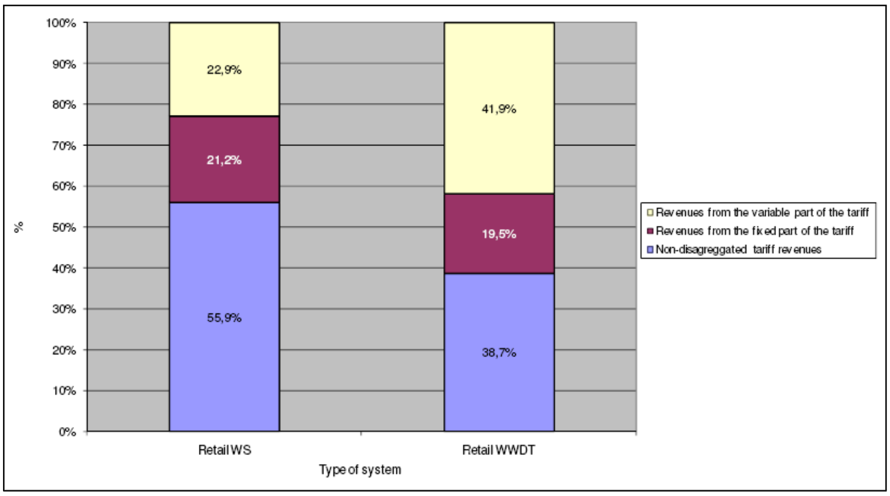
This is in accordance with the position of the Portuguese regulator for the industry (ERSAR, ex-IRAR) which states that "water and waste services imply large investment and maintenance costs, usually long-term highly sunk assets, therefore their tariffs should be composed of an availability part and another one for the use. The latter depends on actual consumption (volume of water supplied or wastewater and waste collected), covering the variable costs associated with the service use level, while the former intends to support mainly the fixed costs originated by the continuous availability of the service which do not depend on the level of utilization" (IRAR (2008*a*)). There was some controversy prior to the publication of Law 12/2008 of February 26 (legislation regarding the protection of the customers of essential public services), due to the fact that it prohibits charging a rent for the water meter (it was a usual practice in Portugal to name the fixed component of the tariff as a water meter rent, which was a property of the water company). Some thought this would mean forbidding the existence of a fixed component in the tariff (permitted by the article 22 of the Decree-Law n. 207/94 of August 06)[21], but the law that was published does allow for the fixed component to exist because, although it prohibits charging for minimum consumption levels it does say in article 8 n. 3 that "for the purpose of the present article, fees and tariffs due to construction and maintenance of public water, sewage and solid waste systems are not considered minimum consumptions" (AR (2008)).

In Portugal, most water utilities use both a fixed and a variable component in the tariffs for water for the several types of customers. We have seen in chapter 1 that, for

[21] Decree-Law n. 207/94 of August 06 contains the legal regime for creating and exploring public and private systems of water distribution and wastewater drainage. Article 22 regulates billing procedures.

example, 97.5% of the water utilities included both components in the tariffs for residential customers in 2005 (for wastewater it is more common to use only one of the two components).

Figure 2.22: Distribution of retail WS and WWDT tariff revenues (2005)



2.6.3 Non-tariff revenues

Figure 2.23 shows the several types of non-tariff revenues collected in the WS activity. More than 1/3 consists of payments for the execution of connection extensions. If we add the fees for the connection of private networks to the public connection extensions we already account for more than half of the non-tariff revenues (except for the year 2005, but that is due to a lower level of disaggregation in the data reported). Other revenues in this category are the charges for the establishment of contracts, the final payments to terminate them, payments to install or remove meters, for repairs, inspections or registration of contracted technicians.

Figure 2.23: Disaggregation of non-tariff revenues in WS (1998-2005)

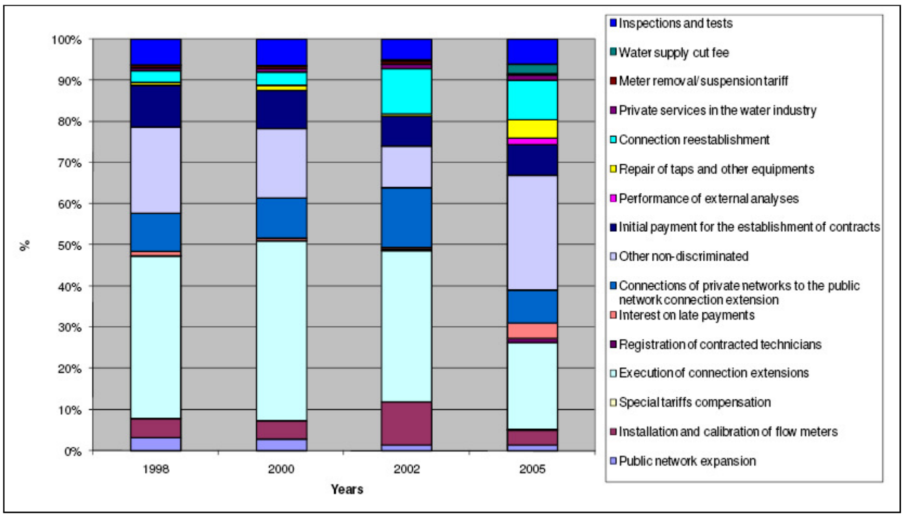
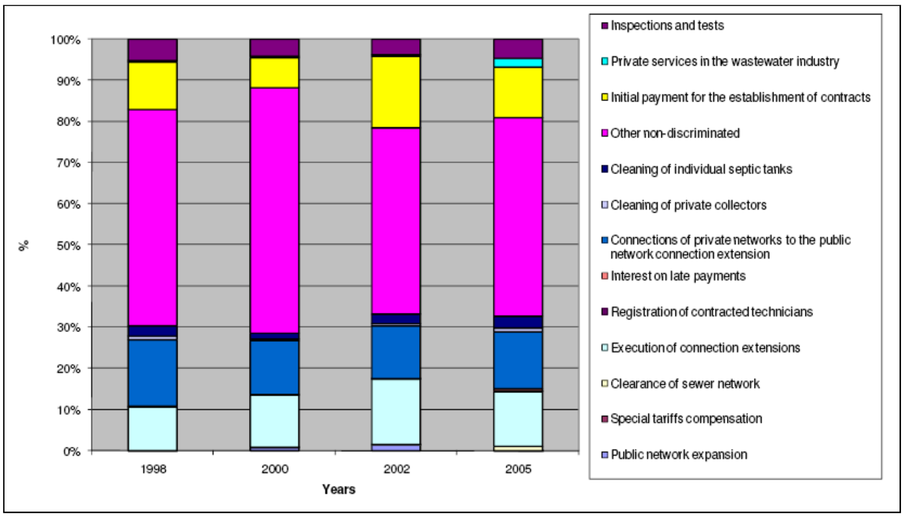


Figure 2.24 shows the disaggregation of WWDT non-tariff revenues. Little more than half of them have been disaggregated in INSAAR. The revenues we find are again payments for the execution of public connection extensions or to connect private networks to them, payments for the establishment or the termination of contracts and inspections. We also find revenues originated from the activities of clearance of sewer networks, or cleaning private septic tanks and other collectors.

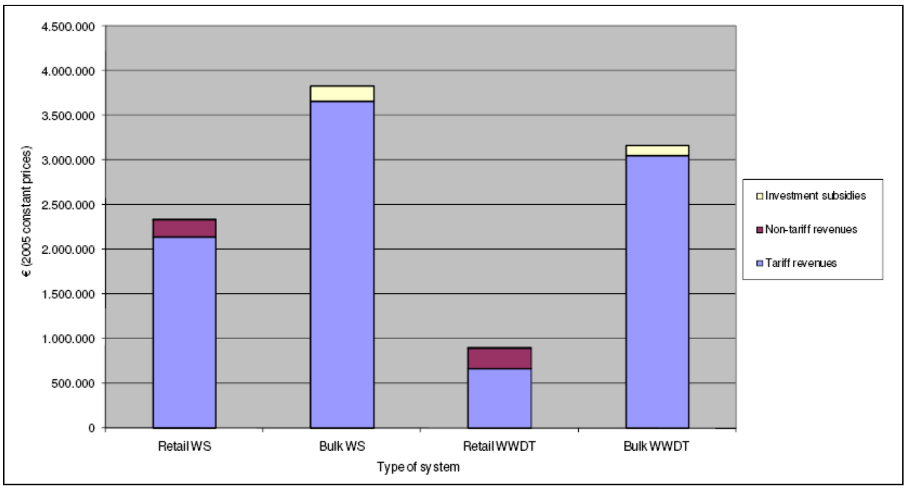
Figure 2.24: Disaggregation of non-tariff revenues in WWDT (1998-2005)



2.6.4 Revenues per utility and unit revenues

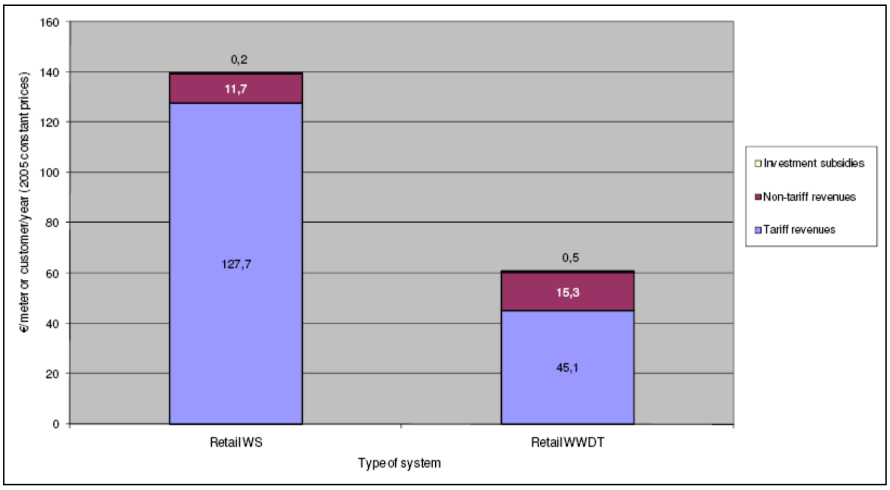
The average amount of revenues from bulk WS activities accruing to a water utility was €3.9 million, while the figure for WWDT was €3.2 million (Figure 2.25). The average amount of revenues per utility was, as expected, much lower for retail activities, €2.3 million for WS and €0.9 million for WWDT. We confirm the finding that, not only are bulk operators larger than retail ones, but also that WS systems collect significantly more revenue than the systems for WWDT, especially at the retail level where on average a WWDT utility collects more than 60% less revenue than the corresponding retail WS utility. The revenues declared to INSAAR are mainly composed of tariff revenues in any of the four types of systems considered.

Figure 2.25: Average revenue per utility in WS and WWDT systems (2005)



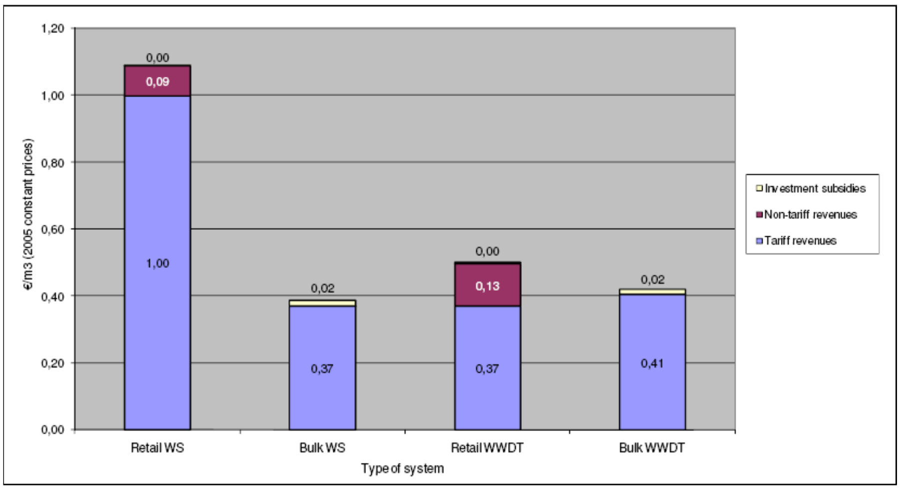
These facts can also be seen from the unit revenues collected per customer in retail WS and WWDT systems. While for WS the annual revenue per customer collected is €139.6/customer/year, the number for WWDT is only €60.9/customer/year (Figure 2.26). These values are insufficient to cover the costs reported in Figure 2.17 as we will conclude in the section regarding cost recovery levels.

Figure 2.26: Annual unit revenues per customer in retail WS and WWDT systems (2005)



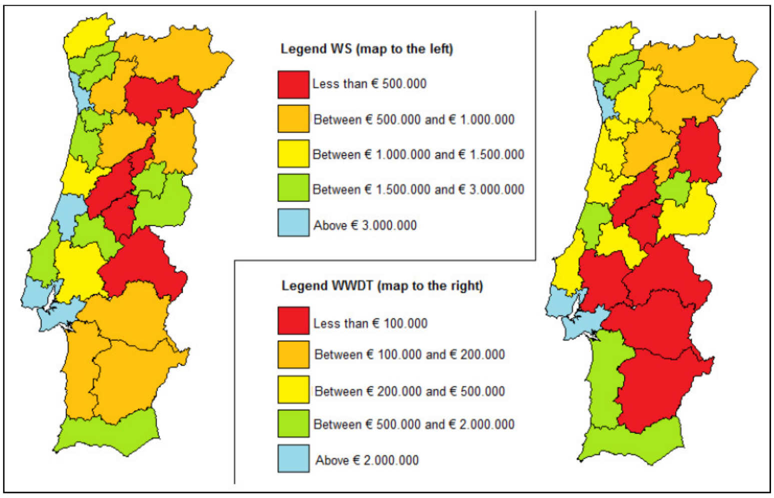
The amount of revenue collected from each m^3 of retail water supplied was on average €1.09, while the revenue collected for each m^3 of retail wastewater drained was only €0.50 (Figure 2.27). The numbers for bulk activities were €0.39/m^3 in WS and €0.43/m^3 in WWDT. The lower values for bulk activities are to be expected because a minimum requirement for revenue collected at the retail level is that it covers the amounts paid to bulk operators for supplying water/draining wastewater to/from retail operators. To this requirement we have to add the need to cover the retail activities' own water distribution/wastewater collection costs.

Figure 2.27: Average unit revenue per m^3 in WS and WWDT systems (2005)



The regional distribution of utilities' turnover in WS and WWDT follows closely the population distribution, as expected, due to the association between retail operators and the country's municipal administrative divisions (Figure 2.28). The larger utilities are therefore located in west and south seacoasts, with the largest ones concentrating in the two metropolitan areas around Lisbon and Oporto.

Figure 2.28: Average revenue per utility in retail WS and WWDT by NUTS III (2005)



Unlike the results for the geographical distribution of costs per customer (Figure 2.17), we do find a clear pattern in the regional distribution of revenues per customer (Figure 2.29). The highest values are found in the more densely populated regions in the west seacoast, especially around the largest cities. In fact, there does not seem to be a clear correspondence between higher costs (due to differences in altitude or in the investments in water and service quality) and higher revenues. Revenues per customer seem to be more related with population density (see Figure 2.19) and income levels (Figure 2.30)[22], which are higher in the more densely populated west coast regions, than with unit costs. This conclusion is suitable for both WS and WWDT systems, but one should notice the difference in scale in Figure 2.29, because WWDT revenues are much lower than in WS.

[22] Purchasing power index shown in Figure 2.30 were obtained from the National Statistics Institute (INE), while the household disposable income per capita is obtained from the data provided by the Ministery of Finance and Public Administration on household taxable income and taxes collected.

Figure 2.29: Average unit revenue per customer in retail WS and WWDT by NUTS III (2005)

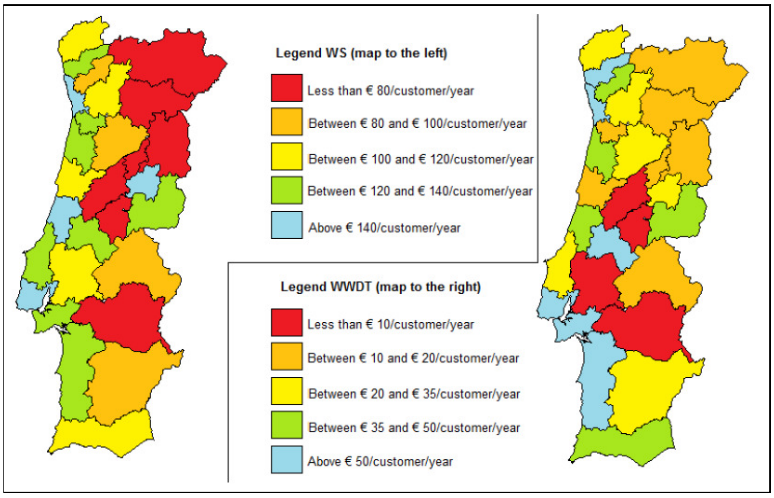
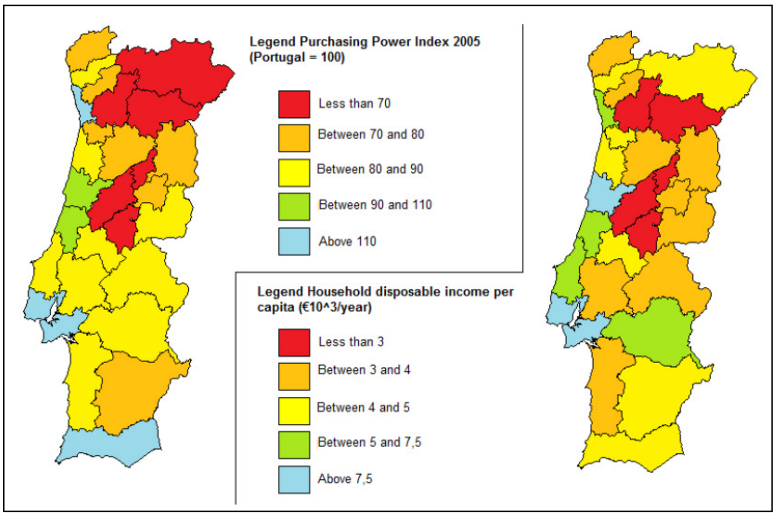
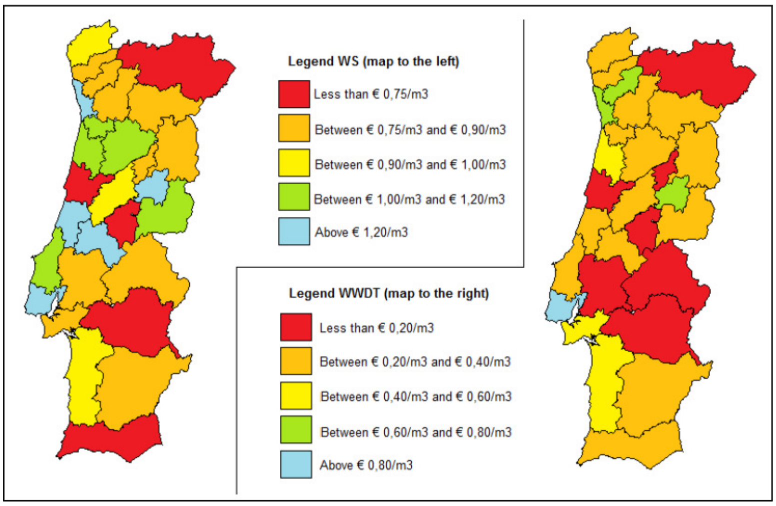


Figure 2.30: Purchasing power index and household disposable income per capita (2005)



The same can be said about the unit costs per m^3, which are much lower in WWDT than in WS. The use of the WS scale in Figure 2.31 for WWDT would turn most of the country to red in the right hand map, clearly showing the difference in the collection of revenue between both systems, but preventing the regional analysis in WWDT unit revenues. For this reason, we chose to have different scales for each type of retail system. From Figure 2.31 we can see that, in general, there is a division between the west coastal regions where revenue collection per m^3 is higher and the inland regions where it is usually insufficient.

Figure 2.31: Average unit revenue per m^3 in retail WS and WWDT by NUTS III (2005)



Similar to the case for costs, we do not find a clear association between the revenue collection amounts and the type of water utility. Table 2.6 shows the unit revenues in retail WS and WWDT systems disaggregated by type of utility. Municipalities are confirmed to have on average a size which is several times smaller than all the other types, both in WS and in WWDT, reflecting their predominance throughout the country, while the alternative management arrangements are more commonly found in the urban centres. The types of utilities with higher average revenues are the public companies (this is a result of the influence of Lisbon, where EPAL[23] manages the WS systems, in a type which

[23] EPAL – Empresa Pública de Águas Livres is a Public Limited Company, whose share capital is held

exists in few municipal counties) and the autonomous municipal services (because they are mainly found in large cities).

Results are not so clear regarding the unit revenues per customer and per m^3. Private and public companies and autonomous municipal services are the types of utilities with higher unit revenues in WS, while municipal companies and municipalities show lower levels of revenue collection. On the contrary, for WWDT, municipalities have some of the highest figures. Public companies show high unit revenues per customer but low unit revenues per m^3 in WWDT, while autonomous municipal services on the other hand show low unit revenues per customer, but not so per m^3. Overall, we do not find an ordering we can clearly associate to a transition from public to private, or from the public service type of management to a more business-like type of management.

Table 2.6: Unit revenues by type of utility in retail WS and WWDT (2005)

	Average revenue per utility (2005) (€)		Average unit revenueper customer (2005) (€/customer/year)		Average unit revenue per m^3 (2005) (€/m^3)	
	Retail WS	Retail WWDT	Retail WS	Retail WWDT	Retail WS	Retail WWDT
Municipality	762 564	506 590	91.3	63.2	0.78	0.54
Autonomous Municipal Services	8 704 821	3 168 946	170.0	55.3	1.38	0.51
Municipal or Intermunicipal Company	4 816 430	1 997 263	136.6	56.2	0.79	0.39
Public Company	11 249 743	2 187 172	194.7	90.8	1.34	0.43
Private Company	5 545 739	2 263 946	175.0	59.5	1.21	0.42
Total	2 338 926	900 929	139.6	60.4	1.09	0.50

2.6.5 Rates of change in revenues

The revenues have experienced significant real growth rates in all four types of systems (Table 2.7 [24]). The evolution of total revenues is naturally determined by the evolution of

entirely by AdP- Águas de Portugal, the public holding company for the industry.

[24] The following cost categories have a significant amount of missing data: non-tariff revenues and investment subsidies. For tables 2.7, 2.8 and 2.9 we only considered the information explicitly reported by the water/wastewater utilities (we only considered those which had information on revenues for the two years under consideration, the % of volume supplied/drained in the latter year by the utilities being considered is shown in parenthesis). To keep missing data from preventing the calculation of cost recovery ratios, the rest of the document will follow the assumption that missing data is due to a lack of reporting of null values for these two revenue categories and interpreted them as such.

tariff revenues, because of their weight on total revenue. With the exception of bulk water, the computed average annual growth rates for revenues fall short of their counterparts for costs. This anticipates an eventual decline in the cost recovery levels, which we will look into in the following section.

Table 2.7: Average annual rate of change in revenues in WS and WWDT (1998-2005)

Type of system	Type of revenues by system	Average annual rate of change		
		98-00	00-02	02-05
Retail WS	Tariff Revenues	2.9% (80%)	2.2% (89%)	0.7% (94%)
	Non-tariff Revenues	4.4% (56%)	15.4% (66%)	9.5% (77%)
	Investment Subsidies	-28.9% (8%)	-0.4% (9%)	2.3% (11%)
	Total Revenues	3.3% (80%)	2.9% (89%)	1.7% (94%)
Bulk WS	Tariff Revenues	18.3% (89%)	6.7% (96%)	-0.7% (93%)
	Non-tariff Revenues	-	-	-
	Investment Subsidies	17.8% (5%)	0.7% 6%)	0.1% (7%)
	Total Revenues	18.3% (89%)	6.4% (96%)	-0.7% (93%)
Retail WW	Tariff Revenues	8.5% (77%)	3.0% (84%)	4.7% (90%)
	Non-tariff Revenues	-21.2% (39%)	14.9% (61%)	-1.6% (74%)
	Investment Subsidies	14.5% (12%)	3.2% (12%)	0.8% (13%)
	Total Revenues	14.3% (77%)	6.9% (84%)	4.0% (90%)
Bulk WW	Tariff Revenues	16.9% (84%)	4.3% (64%)	31.1% (69%)
	Non-tariff Revenues	-	-	-
	Investment Subsidies	-	-	0.0% (7%)
	Total Revenues	11.4% (84%)	4.3% (64%)	32.2% (69%)

Tables 2.8 and 2.9 show that unit revenues for WS systems have even declined in real terms (after inflation is taken into account) during the period 1998-2005, due to a decrease in the real value of the tariff revenues, which reveals that tariff updates have

been insufficient on average to prevent the erosion effect of inflation on tariffs. The gap between revenues and costs for WS systems is thus expected to have increased during the seven-year period being analysed.

WWDT revenues, on the other hand have been increasing at a rate greater than the inflation rate. This effect benefits in part from the fact that some utilities which did not use to charge for the WWDT service have begun to do so. If we compare with the growth rates for unit costs from Tables 2.4 and 2.5 we see that even these increases in unit revenues have been insufficient to keep up with the large increase in unit costs for the case of retail WWDT. For bulk WWDT, the situation is inverted, and the very significant growth in revenues does enable the gap between revenues and costs to be partially diminished.

Table 2.8: Average annual rate of change in per customer unit revenues in WS and WWDT (1998-2005)

Type of system	Type of revenues by system	Average annual rate of change		
		98-00	00-02	02-05
Retail WS	Tariff Revenues	-0.7% (80%)	-1.1% (89%)	-1.9% (94%)
	Non-tariff Revenues	0.7% (56%)	12.0% (66%)	6.8% (77%)
	Investment Subsidies	-32.3% (8%)	-3.9% (9%)	0.7% (11%)
	Total Revenues	-0.4% (80%)	-0.4% (89%)	-1.0% (94%)
Retail WW	Tariff Revenues	4.4% (77%)	-0.5% (84%)	1.8% (90%)
	Non-tariff Revenues	-24.3% (39%)	11.3% (61%)	-4.2% (74%)
	Investment Subsidies	9.4% (12%)	-0.5% (12%)	-0.8% (13%)
	Total Revenues	10.0% (76%)	3.2% (83%)	1.1% (89%)

Table 2.9: Average annual rate of change in per m3 unit revenues in WS and WWDT (1998-2005)

Type of system	Type of revenues by system	Average annual rate of change		
		98-00	00-02	02-05
Retail WS	Tariff Revenues	-1.7% (80%)	-0.1% (89%)	-0.6% (94%)
	Non-tariff Revenues	-0.5% (56%)	13.6% (66%)	8.5% (77%)
	Investment Subsidies	-37.7% (8%)	-1.3% (9%)	0.2% (11%)
	Total Revenues	-1.4% (80%)	0.8% (89%)	0.3% (94%)
Bulk WS	Tariff Revenues	-6.0% (89%)	-1.0% (96%)	-0.6% (93%)
	Non-tariff Revenues	-	-	-
	Investment Subsidies	-52.8% (5%)	-18.5% 6%)	-3.6% (7%)
	Total Revenues	-6.5% (89%)	-1.3% (96%)	-0.6% (93%)
Retail WW	Tariff Revenues	-1.1% (77%)	-1.7% (84%)	0.4% (90%)
	Non-tariff Revenues	-27.3% (39%)	11.5% (61%)	-5.1% (74%)
	Investment Subsidies	0.1% (12%)	-1.2% (12%)	-5.1% (13%)
	Total Revenues	4.1% (77%)	1.9% (84%)	-0.6% (90%)
Bulk WW	Tariff Revenues	8.1% (84%)	10.4% (64%)	18.7% (69%)
	Non-tariff Revenues	-	-	-
	Investment Subsidies	-	-	-50.2% (7%)
	Total Revenues	8.1% (84%)	10.4% (64%)	19.7% (69%)

2.7 Cost recovery levels

In this section we take the information on revenues and costs, described in detail in the previous sections, and compute the cost recovery ratios for the retail and bulk WS and WWDT systems in mainland Portugal. We only show the results for the years 2002 and 2005, where we consider that the available information is enough to perform the analysis. For the previous two years, the information available is much poorer, representing less than 50% of the volume supplied/drained by the utilities in most types of systems. For the latter years of 2002 and 2005, the amount of data reported improves significantly and the utilities on whose data the results can be calculated represent always more that 72% of all volume supplied/drained.

Table 2.10 [25] shows the results for the several types of systems considered. There are three main conclusions to be taken. The first is that cost recovery falls short of 100% in all types and all periods. The revenue collected, mainly through the tariffs is insufficient to cover the costs of the activity. Financial sustainability of the WS and WWDT systems implies the reduction of unit costs, or alternatively the increase in unit revenues. In Portugal there could be efficiency gains that can be seized for example from increasing the scale of the systems by merging neighbouring utilities (see Martins et al. (2008), on the existence of economies of scale for the Portuguese water industry and chapter 6 for conflicting evidence). However if the possible cost reductions are insufficient and if we exclude the possibility of subsidization, due to the legal requirements described in the Section 2 (the user pays-principle in short), we have to conclude then that tariff levels must surely rise to meet the WFD and Water Law requirements of cost recovery in the industry.

The second conclusion is that the situation is less severe in retail WS. This may, however, be an evidence of cross subsidization between the activities of WS and WWDT

[25] The calculated cost recovery ratios in Table 2.10 only consider those utilities for which there is information on all the cost and revenue categories for the two years under consideration (the % of volume supplied/drained in the latter year by the utilities being considered is shown in parenthesis). For non-tariff revenues, investment subsidies, bulk water purchase/wastewater drainage costs, general administrative costs and financial expenditures we followed the assumption that missing data is due to a lack of reporting of null values and interpreted them as such.

Table 2.10: Cost recovery levels for mainland Portugal by type of system (2002-2005)

	Retail WS	Bulk WS	Retail WW	Bulk WW
2002	96% (95%)	63% (98%)	52% (93%)	58% (100%)
2005	91% (93%)	51% (99%)	56% (92%)	53% (72%)

which are usually managed by the same utility at the retail level.

The third result is that, for the 3-year period (2002-2005) for which an analysis is possible, while the situation for WWDT has improved, the contrary has happened for WS. On the one hand, this may reveal a decrease in the cross-subsidization levels, but on the other hand we do not see any evidence that water/wastewater utilities came any closer to full cost recovery as we approach the 2010 deadline set by the WFD (see also Table 2.12).

This results are particularly surprising regarding the bulk water operators. Given that their activity has always been under the supervision of IRAR (now called ERSAR), we would expect them to perform better concerning their financial sustainability levels. Recent conference presentations by one of ERSAR's directors provide the answer to this puzzle (Pires (2007*a*) and Pires (2007*b*)). Pires (2007*a*) states that "IRAR's assessment is that the financial sustainability of wholesale water service operators is "challenging" in one third of the cases and another third is "unsustainable" unless significant change is implemented". It also provides an explanation by reporting that although "structural factors such as scale and demographic concentration play a key role, they do not tell the whole story (...) lack of investment on the retail side means that wholesale operators are not being able to sell the volumes for which they sized their infra-structure and, not only are they selling less, but their customer receivables are also building up (. . .)" and that "the financial bottleneck lies at the retail (municipal) level" where "end-users not being charged the full service costs".

Table 2.11 adds more information about the level of cost recovery in the Portuguese water and wastewater industry, namely regarding the % of utilities which have levels of cost recovery greater than or equal to one.

Table 2.11: Percentage of water/wastewater utilities and corresponding volumes supplied/drained with cost recovery ratios above and below unity in WS and WWDT (2002-2005)

	Retail WS		Bulk WS		Retail WW		Bulk WW	
	2002	2005	2002	2005	2002	2005	2002	2005
% of the water/wastewater utilities with a cost recovery ratio ≥ 1	27.8%	33.1%	18.3%	4.9%	6.2%	6.7%	12.5%	14.3%
% of the water/wastewater utilities with a cost recovery ratio < 1	72.2%	69.9%	81.7%	95.1%	93.8%	93.3%	87.5%	85.7%
% of the volume supplied/drained reported by the utilities with a cost recovery ratio ≥ 1	53.3%	50.2%	2.7%	0.0%	23.6%	25.6%	31.2%	8.8%
% of the volume supplied/drained reported by the utilities with a cost recovery ratio < 1	46.7%	49.8%	97.3%	100.0%	76.4%	74.4%	68.8%	91.2%

We can see that in 2005 only 33.1% of all retail WS utilities collected an amount of revenues sufficient to cover their costs, according to the data reported to INSAAR. Nevertheless they represented 50.2% of the volume supplied. This seems to indicate some degree of association between the size of the utility and the level of cost recovery.

This is also true of retail WWDT, where only 6.7% of the wastewater utilities recover their costs through the revenue, but they represent 25.6% of the volume drained. The same cannot be said of bulk activities where this association is not always so clear. This result is in accordance with Martins et al. (2008), which claims that economies of scale for the Portuguese water industry are mostly found in small and medium-sized utilities.

Overall the conclusions remain that only for WS do we find some evidence of possible financial sustainability of the systems (we must bear in mind our suspicion regarding the underreporting of investment subsidies) and that there is no evidence that the situation has improved.

Our study is not strictly comparable to the official cost recovery calculations performed by INAG/MAOTDR (2005), INAG/MAOTDR (2007), INAG/MAOTDR (2008) and INAG/MAOTDR (2009), because they may have different assumptions or focus on different aspects of the problem (for example, INAG calculates cost recovery levels for residential customers, while we disaggregate between retail and bulk activities[26]). It is nevertheless instructive to look at the official results.

INAG started off by including the results for cost recovery levels in the river basin regions reports required by article 5 of the WFD (INAG/MAOTDR (2005)) and has subsequently reported them in the regular INSAAR reports (INAG/MAOTDR (2007), INAG/MAOTDR (2008) and INAG/MAOTDR (2009)). Table 2.12 shows the results for WS and WWDT separately and in conjunction.

Table 2.12: Cost recovery levels in mainland Portugal in WS and WWDT (2002-2006)

%	WS	WWDT	WS+WWDT
2002	99	54	82
2005	87	57	76
2006	89	46	74
2008	84	50	72

Source: INAG/MAOTDR (2005), INAG/MAOTDR (2007), INAG/MAOTDR (2008) and INAG/MAOTDR (2009)

We find here the same three conclusions drawn before: cost recovery levels fall short of 100%, the situation is worse for WWDT and cost recovery levels have been deteriorating instead of improving. The overall measure computed for the industry sums up the worrisome proof that the Portuguese water and wastewater industry came no closer to meeting the WFD of cost recovery in the past few years. On the contrary, the gap between revenues and costs has increased from 18% to 26% in four years.

The people who intervene in the industry are aware of the problem. Take for example the statement of a former president of the National Water Institute and current president of AdP: "the tariffs for the several water services (drinking water supply, sewage, irrigation and industry) do not reflect totally the costs involved. In many cases, the difference

[26] One possible explanation for some of the differences between our study and the INAG reports regarding the computed cost recovery ratios may be in our separation between retail and bulk activities. For our purposes, it is relevant to consider the costs/revenues from bulk water/wastewater transactions between retail and bulk operators. For INAG, on the contrary, these categories cancel themselves out due to the aggregate nature of their problem for WS or WWDT. It is, thus, expectable that both studies report the same qualitative conclusion but with differences in the exact measure of the deficits found.

between tariffs and costs is immense, up to the point where the financial sustainability of the service is not assured, despite the fact that the investments in infrastructures have been financed with government subsidies" (Serra (2001), p. 284).

Figures 2.32 and 2.33 reveal the regional differences in the cost recovery ratios for retail WS and WWDT respectively, for the years 2002 and 2005. The lowest values for the cost recovery ratios are found in the northeast inland part of Portugal and more recently also in the southern inland part of Alentejo. We have shown previously that, while for the northern regions, the rugged terrain and the dispersion of population settlings may partly explain this results, it is mainly the low revenue collection that is responsible for the low ratios. Political reasons regarding the concern with the income levels of the population in these regions may be the reason for the low levels of the water and wastewater tariffs. The cost recovery levels are higher for the west and south coastal regions, which are more urbanized, more densely populated and have in general higher income levels.

Cost recovery levels are to a great extent lower in the WWDT systems, where only the Lisbon area is found to have a ratio of cost recovery greater than one on average. The overall scenery is dreadful, with a large number of regions presenting cost recovery ratios lower than 0.2. This is natural if we think that one third of the utilities in Portugal did not charge for wastewater at all (see chapter 1). Wastewater activities benefit from the fact that the same utility usually manages both systems, so that cross-subsidization of the WWDT activity is possible.

Figure 2.32: Cost recovery ratios in retail WS by NUTS III (2002-2005)

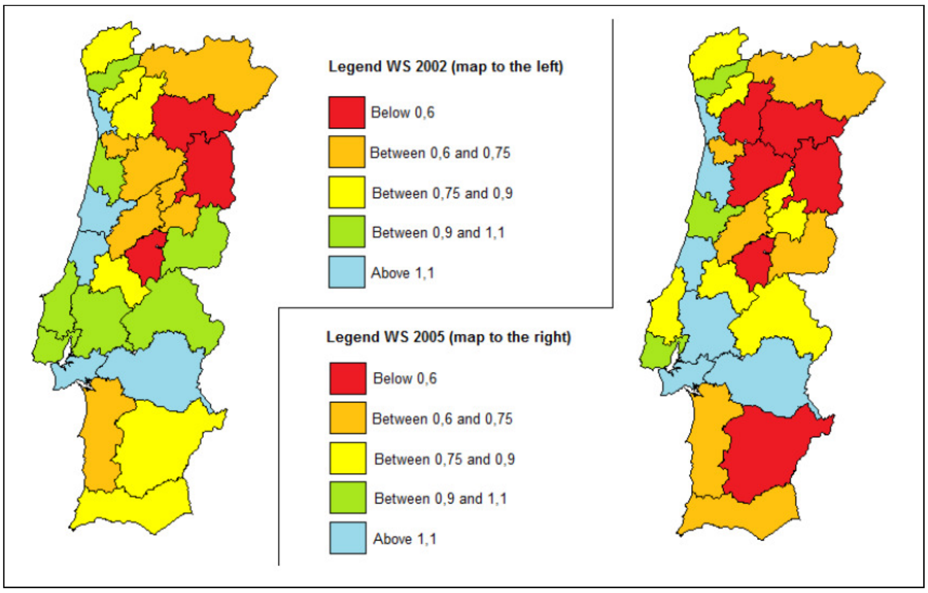
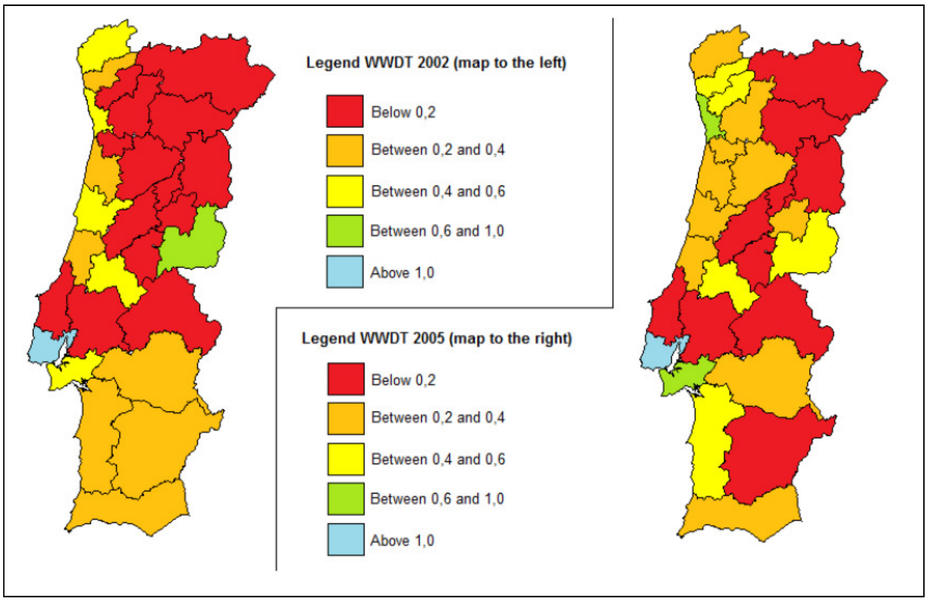


Figure 2.33: Cost recovery ratios in retail WWDT by NUTS III (2002-2005)



If the cost recovery principle from article 9 of the WFD (already reflected in the new Water Law and in the recent Economic and Financial Regime for the Water Resources) is to be complied with then revenue collection must surely rise in the great majority of the municipal counties for retail activities and also in bulk water and wastewater systems. This means that average tariffs will certainly have to increase, something that is even truer of the systems and utilities located in the less densely populated and poorer inland parts of the country. The fact that this may contribute to the worsening of the regional imbalances, has led to the inclusion in PEAASAR II (Strategic Plan for Water Supply and Wastewater Sewage 2007-2013) of the possibility of creating a Tariff Balancing Fund, which would try to keep tariffs of multi-municipal systems supplying bulk water within a price band considered reasonable, through the subsidization of the systems with greater costs[27]. Although the objectives of economic cohesion can have their merit, this type of instrument must be used cautiously to say the least, because this kind of cross-subsidization between different territorial systems can cause losses of efficiency, something that is recognized in PEAASAR II which states that "the existence of an equalization mechanism of this kind can work as a disincentive to the optimization of each system individually considered" (MAOTDR (2007*a*), p. 79).

Looking into the cost recovery levels by type of utility (Table 13), once again we find no evidence of an association between a more private/public ownership or a more or less business-like management and cost recovery ratios. Public companies have the highest figures for this indicator (except for WWDT in 2002), followed by the autonomous municipal services and the municipal companies in WS and by the municipalities in WWDT. On the other hand private companies show low levels of cost recovery in both types of activities. The types of utilities associated with the municipalities have different results in WS and in WWDT. Municipalities themselves have low ratios in WS but have some of the highest

[27]PEAASAR takes advantage of art. 9, n. 1, of the WFD which states that "Member States may (...) have regard to the social, environmental and economic effects of the recovery as well as the geographic and climatic conditions of the region or regions affected" to attempt some convergence in the tariffs, "without nevertheless intending to equalize tariffs in the all country" (MAOTDR (2007*a*), p. 79). It's stated in PEAASAR that "efficiency is not, however, the only value at stake, nor is «full cost recovery» the only principle that can be applied. Equity, regional and individual, is another value to defend and universality and accessibility are also objectives to be achieved" (ibid.).

in WWDT (even though they are still very low). The autonomous municipal services and the municipal companies have high ratios for WS and low ratios for WWDT. Overall no conclusion can be taken from these results regarding the advantages and disadvantages of business-like management and private ownership.

Table 2.13: Cost recovery ratios by type of utility in retail WS and WWDT (2005)

	Cost recovery ratio in retail WS		Cost recovery ratio in retail WWDT	
	2002	2005	2002	2005
Municipality	0,78	0,79	0,57	0,59
Autonomous Municipal Services	1,02	0,94	0,51	0,53
Municipal or Intermunicipal company	1,07	0,96	0,41	0,53
Public Company	1,16	1,23	0,50	0,66
Private Company	0,81	0,74	0,43	0,49
Total	0,95	0,91	0,52	0,56

2.8 Conclusion

In this chapter we updated the results of Monteiro (2007) regarding the analysis of costs and revenues for the Portuguese water and wastewater industry for 2005, halfway between the publication of the WFD and the 2010 deadline for the implementation of adequate cost recovery levels and efficient water pricing, and assessed their evolution between 1998 and 2005. We also presented a brief historical overview of the presence of the cost recovery principle in the Portuguese law regarding the industry.

Overall four main conclusions stand out. First, the need to collect revenues from the users to cover the costs of the service has been present in the Portuguese law for decades and the introduction of the cost recovery principle is prior to the transposition of the WFD through the more recent Water Law. Nevertheless, it always lacked practical implementation. The novelty from the new legislation is the inclusion of scarcity and environmental costs in the set of costs to be recovered through revenue collection and not so much the cost recovery principle in itself. Second, the level of revenues collected by the WS and WWDT utilities is still currently, on average, insufficient to meet the financial costs of their activities (we do not assess here the scarcity and environmental costs). Third, the situation is worse in the case of WWDT than in WS revealing evidence of cross-subsidization within the utilities which manage both systems. Fourth, the situation has worsened in recent years.

The lowest cost recovery ratios are found in the northeast inland part of the country and in the southern part of Alentejo. While in the former reasons can be found in the rugged terrain and the disperse nature of the population settlings to justify higher unit costs, the same cannot be said of the latter. Nevertheless the main reason for the deficits found is mainly the lack of enough revenue collection through the tariffs in both cases. Political concerns with the low levels of income in these regions may be behind the low levels of tariffs for water and wastewater.

If the cost recovery principle from article 9 of the WFD (already reflected in the new Water Law and in the recent Economic and Financial Regime for the Water Resources) is to be complied with, then revenue collection must surely rise and average tariffs will have to increase. This is even truer of the systems and utilities located in the less densely populated and poorer inland parts of the country. Caution should be used in the use of instruments such as the Tariff Balancing Fund mentioned in PEAASAR II to promote regional economic cohesion, as it distorts incentives to optimize the systems and generates efficiency losses.

We find no clear evidence of an association between the cost recovery levels (or the unit costs or revenues) and the type of utility. The results do not seem to favour neither public nor private ownership, nor do they shed light on the best management model (public service vs. business-like management).

The new Water Law and the corresponding Economic and Financial Regime of Water Resources transposed the full cost recovery principle (including scarcity and environmental costs) from the WFD. The new water resources charge, in force since July 2008, is a step forward towards the internalization of the scarcity and environmental costs and will have to be reflected in the tariffs consumers face. For adequate cost recovery to be achieved by 2010, additional tariff increases will have to happen, so that unlike previous legislation, the new legal regime for water resources should be applied this time.

Chapter 3

Water Pricing Models: a Survey

3.1 Introduction

There is an abundant literature on water pricing. Several studies on the impact of the water price on water demand are published every year. Articles comparing the properties of different price schemes or pointing out the difficulties in implementing more efficient pricing rules are also frequent, with a diversity of case studies on implementing water pricing reforms. However, theoretical water pricing models are scarcer and more disperse in the scientific literature. They are important to the water utility manager or to the water supply industry regulator who have to present precise water pricing schemes to customers in the specific conditions they operate in. Furthermore, the Water Framework Directive approved in 2000 requires that by 2010 (art. 9, n. 1) a price policy must be defined not only to recover the costs of the resource, but also to provide incentives for consumers to use water efficiently, contributing to the established environmental targets. This chapter attempts a systematic review of the existing literature on water pricing models.

Most issues dealt with here are not specific to the water sector. Marginal cost pricing (Dupuit (1844), Coase (1946) and Coase (1970)), capacity constraints and peak-load pricing (Boiteux (1949)), revenue requirements (Allais (1947)) and nonlinear pricing (Wilson (1993)) are subjects which have been researched in the more general framework of regulated public utilities for a long time now. Brown and Sibley (1986) present the first systematic exposition of the previous contributions to the theory of public utility pricing.

3.2 Existing water pricing schemes

There is a bewildering diversity of actual water prices and rate structures implemented by different water utilities, even within areas where geographical conditions are similar.

The customer may be required to pay a connection fee to gain access to the water supply system. A service charge is often required to cover costs that are not related to the quantity consumed (like metering cost; in fact, service charges are also frequently called meter charges) or to guarantee cost recovery in situations where price differs from average cost.

A quantity-related price is a consensual requirement for efficiency but in reality volumetric pricing can be implemented in a variety of ways. The utility may implement a uniform rate, which in turn can be based on the average or on the marginal cost of water supply. This uniform price may be combined with rebates or discounts to assure that no excessive profits are generated in the cases where marginal cost related prices exceed average costs. Another frequent solution is the implementation of nonlinear pricing with block tariffs (tiered pricing). Decreasing block tariffs (DBT) may be supported where a natural monopoly is recognized, while increasing block tariffs (IBT) are often associated with the implementation of marginal cost pricing with equity or poverty alleviation concerns, or simply to signal potential scarcity or capacity constraints.

Other possible variations are the differentiation of price structures according to customer classes or seasons. Even the adoption of time-of-day pricing has been advocated for the water industry, although it is more frequent in the electric power industry.

A frequent solution is the adoption of a two-part tariff, which consists in the combination of a service charge with a uniform volumetric price, but other water pricing and allocation methods are possible.

Surveys of water pricing schemes and water rates are often published by the national institutes concerned with the environment in general or the water industry in particular. A few examples can be pointed out:

- in 2006, the American Water Works Association (AWWA) together with Raftelis Financial Consultants, Inc. surveyed the water and wastewater rates, fees and charges of

230 U.S. water utilities and 164 wastewater utilities[1];

- in 2002, the U.S. Environmental Protection Agency (EPA) published the report "2000 Community Water Systems Survey" with operating and financial information for approximately 2000 water utilities in the USA;

- Environment Canada is preparing an update for 2006 of its periodical Municipal Water and Wastewater Survey (MWWS), which includes data on water use and pricing;

- The Water Services Regulation Authority in England and Wales (OFWAT) publishes yearly reports on water and wastewater charges;

- the Portuguese National Water Institute (INAG) has implemented in 2002 a periodic National Inventory on Water Supply and Wastewater Systems (INSAAR), which includes data on the water pricing schemes and for which updates for 2005 and 2006 and 2007 have already been released.

Studies on actual water pricing schemes are also available. For example, Hewitt (2000) describes the pricing methodology supported by the AWWA, Montginoul (2007) and Garcia and Reynaud (2004) describe the French water sector, Embid-Irujo (2005) presents water pricing practices in Spain, Bakker (2001) reports pricing practices in England and Wales, Howe (2005) describes the water pricing institutions in the United States and in Canada, Garrido (2005) surveys the major case studies and practical applications of water pricing in Brazil and Bithas (2008) describes the water pricing policies in the cities of Athens, Amsterdam, London, Seville and Tel-Aviv. OECD (1999*a*), OECD (2003*a*) and OECD (2009) review water tariffs in OECD countries. Other case studies for specific countries are often easy to find.

3.3 Water pricing models

The articles surveyed present theoretical water pricing models which concentrate on particular questions of water pricing. The questions addressed are varied and numerous. Table 1 sums up the main ones and the papers that deal with each one.

We now discuss in greater detail the most important issues referred to in Table 3.1.

[1] An update of this bi-annual survey has been released for 2008.

Table 3.1: Questions addressed by the water pricing models

Questions addressed	Publications	
Average vs. Marginal Cost Pricing	Hirshleifer, de Haven and Milliman (1960) Riordan (1971*a*) Dandy, McBean and Hutchinson (1984) Zarnikau (1994)	Brill, Hochman and Zilberman (1997) Chambouleyron (2004) Briand (2006)
Seasonal or temporal variations	Gysi and Loucks (1971) Riley and Scherer (1979) Manning and Gallagher (1982) Dandy et al. (1984)	Zarnikau (1994) Beare, Bell and Fischer (1998) Elnaboulsi (2001) Schuck and Green (2002)
Capacity constraints or expansion decisions (Peak-load pricing)	Hirshleifer et al. (1960) Riordan (1971*a*) Gysi and Loucks (1971) Riley and Scherer (1979) Manning and Gallagher (1982) Swallow and Marin (1988) Dixon (1990)	Zarnikau (1994) Beare et al. (1998) Elnaboulsi (2001) Griffin (2001) Loehman (2004) Elnaboulsi (2009)
Scarcity	Moncur and Pollock (1988) Zarnikau (1994) Elnaboulsi (2001) Griffin (2001)	Schuck and Green (2002) Loehman (2004) Briand (2006)
Revenue requirements	Hirshleifer et al. (1960) Freedman (1986) Collinge (1992) Zarnikau (1994) Kim (1995) Brill et al. (1997)	Decaluwé, Patry and Savard (1999) Griffin (2001) Schuck and Green (2002) Loehman (2004) Diakité, Semenov and Thomas (2009) Schoengold and Zilberman (2009)
Optimal number of metered connections	Barrett and Sinclair (1999) Griffin (2001)	Chambouleyron (2004)
Efficiency of block tariffs	Gysi and Loucks (1971) Brill et al. (1997) Elnaboulsi (2001)	Castro-Rodríguez and Delicado (2002) Cardadeiro (2005) Elnaboulsi (2009) Schoengold and Zilberman (2009)
Second-best pricing	Kim (1995) Decaluwé et al. (1999) Elnaboulsi (2001) Schuck and Green (2002)	García-Valiñas (2005*a*) Elnaboulsi (2009) Diakité et al. (2009)
Optimal derivation of nonlinear pricing schemes	Elnaboulsi (2001) Loehman (2004) Cardadeiro (2005)	García-Valiñas (2005*a*) Elnaboulsi (2009) Schoengold and Zilberman (2009)
Customer heterogeneity	Brill et al. (1997) Elnaboulsi (2001) Castro-Rodríguez and Delicado (2002) Chambouleyron (2004)	Cardadeiro (2005) García-Valiñas (2005*a*) Elnaboulsi (2009) Diakité et al. (2009) Schoengold and Zilberman (2009)
Equity	Castro-Rodríguez and Delicado (2002) García-Valiñas (2005*a*)	Diakité et al. (2009) Schoengold and Zilberman (2009)
Storage	Riley and Scherer (1979) Manning and Gallagher (1982)	Beare et al. (1998)
Groundwater	Moncur and Pollock (1988)	Schuck and Green (2002)
Conjunctive use of surface and groundwater	Brown and McGuire (1967)	Schuck and Green (2002)
Utilization of water as an input	Brown and McGuire (1967) Brill et al. (1997) Beare et al. (1998)	Schuck and Green (2002) Briand (2006)
Constraints regarding water price changes	Dandy et al. (1984)	
Pricing of wastewater services	Elnaboulsi (2001)	
Multi-product water supply	Kim (1995)	Briand (2006)
Dynamic programming techniques	Riley and Scherer (1979) Dixon (1990) Beare et al. (1998)	Decaluwé et al. (1999) Briand (2006)
Simulation techniques	Gysi and Loucks (1971)	Riordan (1971*a*)
Computable General Equilibrium (CGE) models	Dixon (1990) Decaluwé et al. (1999)	Briand (2006)
Discounting	Manning and Gallagher (1982)	

3.3.1 Average vs. Marginal cost pricing

The oldest debate in the literature on water pricing is whether to price water by its average cost (based on financial reasons of cost recovery) or by its marginal cost (based on the economic reasoning of promoting an efficient use of the resource). As we will see, this is a closed debate by now, if not in actual practice, at least among economists.

Essentially, a resource is considered to be used efficiently if the benefit for society from consuming the last or marginal unit of the resource is the same as the cost of obtaining it (including the opportunity cost of foregoing other alternative uses). If the price of the resource is equal to its marginal cost, then the consumer can adequately compare the benefits she obtains with the costs she imposes with her consumption decision. If the unit price differs from marginal cost, consumption levels will be either too high (for prices below marginal costs) or too low (for prices above marginal costs) in relation to the socially optimum level of consumption.

Hirshleifer et al. (1960) support the use of marginal cost pricing of water, opposing the practices of average cost pricing, for the efficiency reasons mentioned above. They also support price differentials for on-peak and off-peak demand. For example, seasonal peaks in water demand in the summer would require the introduction of a summer peak-load differential or surcharge in price. This question is dealt with in further detail in the next section.

The case of a public water agency supplying a set of irrigation districts was considered by Brown and McGuire (1967). The water agency takes the decision about how much bulk surface water to buy, how to price irrigation districts for the water distributed and how to price groundwater withdrawals within the districts to assure an efficient water use. The pricing policy that results from maximizing the system's welfare (the water agency's profits plus the irrigation districts' benefits from water use) is one of the first marginal cost pricing rules derived in a complete water model. Surface water price must be equal to the marginal distribution cost in each district plus the unit cost of purchasing bulk water and groundwater price must be equal to the direct marginal cost of pumping plus the sum of the discounted marginal effects on future pumping costs via future pumping lifts. Average cost pricing is not even considered in this early article. The only expressed concern about the financial viability of the water agency is the allocation of the groundwater pumping revenues to cover the deficits of the marginal cost pricing policy, but the balancing of the budget is not guaranteed in the model.

Riordan (1971*a*) compares typical average cost pricing techniques with her proposal of multistage marginal cost pricing, where price is equated to short-run marginal cost and varies accordingly with demand increases and the several stages of optimal capacity expansion. She finds that the latter is able to provide a 10-20% increase in total net benefits.

Dandy et al. (1984) analyze a constrained water pricing method (where there are constraints on the magnitude of price changes allowed in a change from average cost pricing to an optimal marginal cost pricing rule). They find that such a scheme, while being less efficient than the optimal water pricing derived in their model, can still increase benefits to society when compared to actual average cost pricing practices.

Zarnikau (1994) develops a model of spot market pricing for water (short-run marginal cost pricing), based on previous work done for the electric power industry. Again, this water pricing system is more efficient than average cost pricing, especially when short-run marginal costs vary over time or when water becomes scarce and rationing methods have to be found. This system would also provide information about the customers' valuation of system enhancements or capacity increases through the amounts they actually pay when capacity constraints are binding.

Irrigation water pricing is considered again by Brill et al. (1997) who compare both pricing policies in the context of an irrigation water district facing a balanced budget constraint and heterogeneous farmers and confirm the superiority of marginal cost-pricing regarding efficiency. Their article goes beyond this objective, however, by assessing the efficiency of block-rate pricing and water trading schemes.

Chambouleyron (2004) compares both pricing schemes under different metering regimes (universal metering and optimal metering). He also shows that marginal cost pricing is always the most efficient pricing regime.

Finally, Briand (2006) uses a sequential dynamic computable general equilibrium model to arrive at the same result, in the specific case of the Senegalese economy. She simulates an initial phase of capacity expansions followed by increasing resource scarcity due to climatic shocks and concludes that marginal cost pricing mitigates the negative effects from water shortages and improves the household's welfare (the resulting deficit in the water utility's budget is assumed to be financed by the government).

3.3.2 Seasonal or temporal variations

Having seen that marginal cost pricing is common sense in the literature nowadays, the next question is how to deal with time-related variations of marginal cost and whether they should be reflected in the water price.

Gysi and Loucks (1971) extend the analysis made by Riordan (1971*a*) about the investment-pricing decisions of a monopolistic public utility by considering block rate water tariffs and seasonal variations in prices. They disaggregate nonlinear demand functions for five residential sectors, based on the dwelling value. Their results point out the advantages of an increasing block rate schedule combined with a summer price differential.

The spot-market pricing system developed by Zarnikau (1994) derives prices that vary with location and time (including time of day). Some additional charges may be customer specific. Short-run marginal costs must include, besides operating costs, the costs imposed by capacity constraints or by the scarcity of water resources, to ration the available water to the highest value uses.

The author also points out some questions regarding an actual implementation of the system. Additional charges related with capacity constraints or water scarcity should be set at a level which assures that existing demand at such prices can be met by the existing water supply. This requires the knowledge of the price-elasticity of demand. Price changes would be very frequent (including different charges for different periods of the day with frequent price changes in a single day). However, such frequent changes may cause instability in the long-term decisions of customers like investing or not in water saving technologies. The author does not address this issue. The adoption of this kind of pricing system would require the implementation of a communications system to keep customers permanently informed of the possibly frequent price changes, as well as more frequent meter readings, possibly through remote meter reading technology using telephone lines or cable television. Consumers are expected to respond to time-of-day-pricing or spot market pricing by changing their consumption from periods with higher prices to periods with lower prices.

Finally, it should be noted that the model developed by Zarnikau (1994) ignores the implementation costs of this water pricing system. For spot-market water pricing system to be worth implementing its benefits must outweigh its costs. The author uses an analogy with implementation practices in the electric power industry to suppose that it might only be beneficial to implement this water pricing system in the class of large water users such as industrial or commercial users or golf courses. The residential class could remain with other more traditional water pricing systems. For this dual pricing system to be effective, curtailment premiums (additional charges due to capacity constrains or scarcity) imposed on large users would have to be overstated, because residential customers would not be given the same price signals.

The optimal irrigation water pricing found in Beare et al. (1998) incorporates cyclical variations of water inflows and moisture needs and a stochastic process representing uncertainty about those inflows and water availability. They also consider the role played by capacity constraints of river dams and distribution channels and by the existence of environmental flow requirements. They use simulation techniques on a hydroeconomic model of the Murrumbidgee catchment of the southern Murray Darling Basin in southeast Australia. Their main result is that seasonal uncertainty affecting both water demand and availability raises the average opportunity cost of water use over the irrigation season, due to storage capacity constraints.

Schuck and Green (2002) develop a model of water pricing with the ability to reflect variations in water supply on the price of water (supply-based water pricing model) and to consider the revenue constraints of the water providing agency. It does so in the context of a conjunctive use system with stochastic surface water flows. The model combines the techniques of conjunctive use systems management and second-best (Ramsey) water pricing. It considers the case where water is an input in the activity of farmers, and it also allows for the possibility of recharging the aquifer with excessive surface water in bountiful years, although not without a cost. The authors assess the impact of the pricing policy on water use, acreage (land use) and energy use, through an application to a water district from California using simulation techniques.

The social planner's model that is developed indicates the existence of a U-shaped cost curve with higher cost in times of drought (due to pumping costs) and times of plenty (due to recharging costs). They conclude, however, that while the pumping costs incurred by the irrigation district in periods of drought should be added to the remaining usual costs in average supply periods, the recharging component of the costs should be subtracted from the remaining costs in the determination of the water price to encourage growers to use more surface water. This would avoid the costs of recharging the water in the aquifer. This argument seems to make sense at first, but the fact that it is not mathematically consistent with the cost equations and the marginal cost pricing rule raises the question of its actual correctness. Maybe the argument is erroneous in thinking only in the short-term. The problem in the paper is one of dynamic optimization, therefore, the short-term argument that the irrigation district will try to avoid the cost of having to recharge the aquifer in times of plenty, may be wrong because it is not considering the value in the future of having water in the aquifer to pump in times of drought. By introducing the possibility of recharging the aquifer, the authors created also a storage problem that is not entirely dealt with in the paper. Notice that, instead of recharging and facing the corresponding costs, the district could waste the excessive water, thus not needing to lower the price to avoid the recharging costs! The problem in this paper is twofold: recharging the excessive water is faced as an obligation and not as a possibility; in the recharging decision the authors are only considering the present costs and not the future value of greater aquifer height (reducing future pumping costs in periods of drought).

The results indicate that the adoption of the supply-based pricing policy proposed reduces water demand and energy use and increases fallowing (leaving the land uncultivated) in periods of drought, adjusting agricultural activities to the water supply of each period. However, future research would have to validate these conclusions after correcting for the problem mentioned above and considering the value of storage in smoothing water supply over time. The development of this kind of seasonal water pricing methods must explicitly take into account the possibility of water storage.

3.3.3 Capacity constraints or expansion decisions

The determination of water price when facing capacity constraints has been an issue of research for a long time now, not only for water supply, but also for other public utilities like electric power supply. This decision is usually studied together with the decisions to expand the system. One important conclusion is that peak-load pricing (charging long-run marginal costs to peak consumers and short-run marginal costs to off-peak consumers) may delay investment in system expansion in relation to other more inefficient pricing schemes.

Riordan (1971*a*) develops a model of optimal water pricing and investment by a publicly owned or regulated monopoly called multistage marginal cost pricing. The model is based on a short-run marginal cost pricing rule. When supply approaches capacity the price necessarily rises, keeping demand within capacity constraints. Dynamic programming techniques are employed to derive the optimal capacity expansions and their adequate timing. Riordan (1971*b*) applies the model to urban water supply treatment facilities.

Riley and Scherer (1979) deal with the issue of peak-load pricing when supply and demand are both seasonal and there is the possibility of storage. They apply it to water pricing where seasonal supply and demand are out of phase. The article combines the literatures of peak-load water pricing and reservoir planning and operation.

Manning and Gallagher (1982) extend the model developed by Riley and Scherer (1979) to treat two additional problems ignored in the latter article: the importance of discounting (time preferences) to pricing policies and the derivation of an optimal discrete approximation to optimal continuous pricing policies. To do so they use the concept of arbitrage between different periods of time enabled by water storage. The arbitrage possibility is not so much based on the stochastic nature of water inflow, they argue, but more on its seasonal pattern. Arbitrage would be profitable in periods when there is an increase of the natural price of water (the price that continuously equates time varying supply and demand). Water storage would be more worthwhile the more price-inelastic is the demand for water.

They find that, in the absence of storage capacity limits and direct costs of water storage (other than the opportunity cost of keeping the water in storage instead of selling it), the price of water held in storage must rise at the rate of interest and the effect of discounting is to cause a cycle in the price of water (the initial price of water is set to equate total water inflow and total water demand over the cycle). If $p(t_1)$ is the price at which we could be selling an additional unit of water at time t_1, $p(t_2)$ is the price at which we will be able to sell it at time t_2 if we keep it in storage from t_1 to t_2, and r is the interest rate, then is must be that $p(t_2) = p(t_1)er^{(t_2-t_1)}$, otherwise arbitrage would be possible between the two periods (remember it has been assumed there were no direct storage costs).

The authors consider that the rule created by Hotelling (1931) for the optimal price of an exhaustible resource available in a fixed quantity is just a limit case of the kind of storage problem they face, with the inflow of resource limited to an initial endowment in the first period and with no limit on the ability of storage capacity to carry this quantity over to the following periods.

The authors also find that if there are limits to storage capacity, water prices can rise faster than the interest rate when the capacity constraints are binding (when the water storage facilities are full). The optimal water storage capacity derived will depend negatively on the price-elasticity of demand and positively on the planning horizon length.

The model developed by Dandy et al. (1984) to determine optimal water pricing and optimal magnitude and timing of capacity expansions is an extension of the work done by Hirshleifer et al. (1960) and Riordan (1971*a*). As mentioned above, they consider also the political feasibility of the optimal rule derived.

This type of simultaneous decision models about the optimal water pricing and optimal capacity expansion decisions was translated into a general equilibrium framework by Dixon (1990) and applied to the context of water supply in Melbourne.

Some authors have attempted to estimate the welfare gains from applying efficient prices when faced with capacity constraints. Swallow and Marin (1988) are critical of pure short-run marginal cost pricing in the presence of capacity constraints due to the induced price fluctuations and point out that using a weighted average of the annual marginal short run and capacity expansion costs to create a constant price results in 98.5% of the net benefits produced by the efficient pricing policy. Renzetti (1992) on the other hand estimates a 4% gain in welfare, but he compares the inefficient average cost pricing policy with peak-load pricing in a situation of seasonally differentiated demand (Ramsey pricing is also considered but produces less efficient results because it does not include a fixed charge).

3.3.4 Scarcity

Scarcity is a more recent concern than capacity constraints, reflecting the fact that the usual approach to rising water demand in the past was to expand the water supply system.

Moncur and Pollock (1988) deal with the problem of determining the scarcity rent of water. They consider the case of a water utility with groundwater as its only source, and use a nonrenewable resource efficient extraction model to determine the scarcity value and the efficient path of price in the future. They calculate the scarcity value through the consideration of the future increase in costs originated by the necessity to use costly backstop technologies (such as desalination or trans-basin diversions) to satisfy water demand. They apply their model to Honolulu and find the scarcity value to be approximately twice the current water charge. An efficient price would have to equal marginal cost and the latter should include not only accounting costs but also opportunity costs reflected in the scarcity rent for water. This implies that efficient pricing of water in Honolulu would require its current price to triple.

Elnaboulsi (2001) and Loehman (2004) use a constraint on the water available which, when binding, allows the determination of the shadow value of water resources. This opportunity cost is reflected in the price charged.

Griffin (2001) demonstrates that the price should also include nonaccounting opportunity costs such as: marginal value of raw water (surface and fully renewable ground water sources, in scarcity situations); marginal user cost (to take into account the sacrifice of future uses in unrenewed groundwater supplies); marginal capacity cost (when the water supply enabled by the capacity installed is less than the water demand).

In the computable general equilibrium model of Briand (2006), scarcity is included in the model, after a first phase of water availability increase to reflect supply enhancing policies, through the consideration of a decrease in water availability due to climatic shocks, generating hydrologic deficits when coupled with demand and demographic growth.

3.3.5 Revenue requirements

Marginal cost pricing does not ensure that the water utility generates enough, and just enough, revenues to cover costs (including a reasonable amount of profit to guarantee the involvement of private firms in the industry). Some authors, like Zarnikau (1994), warn us that marginal costs may fall below average costs, which is the situation to be expected in capital-intensive industries like water supply. Others, like Collinge (1992) point out that despite the fact that water utilities are commonly viewed as a natural monopoly due to capital costs, it is not straightforward that the marginal cost falls below the average cost. Because cheaper sources of water are naturally used before other more expensive sources, marginal cost can rise above the average cost of water supply. Therefore, marginal cost pricing can raise a problem to the water utility and its regulators, not because of insufficient revenue, but because it would generate excessive profits. Using marginal cost pricing in a situation where average cost is lower than marginal cost can be an efficient way to raise revenues. Nevertheless, it is generally not allowed, namely because it has a "regressive incidence", hurting the poor the most, since water expenses have a greater weight on their budget. Balancing the budget of the water utility is therefore an objective on the same level of importance as achieving economic efficiency.

Hirshleifer et al. (1960) consider five alternatives to ensure the financial viability of the water utilities which adopt marginal cost pricing in a situation of natural monopoly (with declining average costs): government subsidies; voluntary contributions from customers to ensure water supply; declining block-tariffs; two-part tariffs; separation of customer classes which face different prices (not all necessarily equal to the marginal cost). The authors favor the adoption of declining block tariffs first and two-part tariffs as a second choice.

Freedman (1986) develops a model with the aim of keeping the water utility's budget close to zero. Although the title claims this is an article on water pricing, in fact the model developed only deals with the profit the water utility should target in each year, saying nothing about the prices or tariff structures it should implement to reach the intended profit.

Collinge (1992) proposes a solution to price water efficiently without generating excessive profits for the water utility or excessive burdens for the consumers. The proposal is based on a system of tradable discount coupons ("marketable rights to buy water at prices below marginal replacement costs") with expiration dates, issued by a single water supplying agency. They give the consumer a discount with a value equal to the difference between the marginal and the average cost of water supply (assuming that the average cost falls below the marginal cost). One of the biggest advantages of this proposal is the fact that it only requires information about the cost of existing and additional supply sources, without requiring information on consumer demand (this is a general advantage of water trading schemes). Moreover, the implementation of marginal cost pricing would ensure efficiency, while the issuing of a limited number of discount coupons could balance the water utility's budget.

Zarnikau (1994) mentions some other measures pointed out in the literature to fulfill the revenue requirement, even if sacrificing efficiency in part. These measures are to add (or subtract) a fixed charge to the water bill, to multiply the prices by a fixed factor or to adjust the prices in inverse proportion to the customer's price elasticity of demand. The latter is called Ramsey pricing. When average price is higher than marginal price, the remaining revenue, not ensured by marginal cost pricing is obtained in this method through additional charges/higher prices on the customers with less elastic demand functions.

Kim (1995) derives second-best optimal prices for water supply by a water utility with two products: residential water and nonresidential water. A second-best Ramsey pricing rule is used to assure the balancing of the supplier's budget. The author associates the estimation of a translog multiproduct joint cost function for the water supply industry with given price elasticities of demand for both products, avoiding a simultaneous estimation of both the demand and supply functions.

The results point to a higher price for residential water, which has a lower price elasticity of demand, therefore the budget balancing task falls mainly on residential users. The actual prices are found to be close to the second-best prices derived in the article (no more than a 10% increase in prices would be needed to turn actual prices into second-best prices). The author also finds some evidence of the existence of economies of scope.

García-Valiñas (2005*a*), Elnaboulsi (2009) and Diakité et al. (2009) also use Ramsey pricing to consider revenue requirements in their water pricing models. García-Valiñas (2005*a*) uses Feldstein's proposal (Feldstein (1972)) to adjust Ramsey pricing by using the marginal utility of income to weight individual surpluses in order to reduce the regressivity associated with IBT. Diakité et al. (2009) also deals with equity issues through the introduction of an additional "restriction that a minimum amount of water be supplied at the lowest marginal price possible".

Brill et al. (1997) consider a balanced budget constraint on the construction of their water payment function and use historical water use rights to "redistribute" the excess profit that marginal cost pricing (above average cost, given the models assumptions) would generate.

The application of Ramsey pricing on a general equilibrium model was carried out by Decaluwé et al. (1999) in a model for the Moroccan economy. Although Ramsey pricing does not outperform marginal cost pricing regarding efficiency results, it does allow the elimination of water subsidies to the water agency with a positive impact on water conservation.

Griffin (2001) proposes a tariff structure for water that aims both at efficiency and revenue neutrality of the water utility. He focuses on water supply, setting aside the issues of wastewater, reliability, peak loads, different customer classes, different service capacities and seasonality. The author examines three type of decisions: water consumption by each customer; continuation of service by existing customers; enrollment decisions by prospective new connections. For each of these decisions the author derives the efficient level, which maximizes the present value of net social benefits.

Afterwards, the author proposes a rate structure that achieves these efficient levels while keeping the utility's budget balanced. The rate structure consists of a two-part tariff with a fixed meter charge per period plus a volumetric charge based on the marginal cost of water to achieve efficiency. A connection fee is also charged. In order to achieve revenue neutrality, a water consumption threshold is determined. Consumption below the threshold generates a credit to the consumer that may turn into a payment to the customer if the credit exceeds the meter charge. The correct parameterization of the threshold (and remaining price-related parameters) enables the balancing of the budget.

The author claims that the tariff structure he proposes is more general than the usual two-part tariff because: it does not assume a structure for the cost function (decreasing or increasing); it separates the problems of efficient allocation of water resources and nonwater resources (associated with distribution and metering).

3.3.6 Metering

Barrett and Sinclair (1999) investigate whether the policy of allowing households to choose if their water consumption will be metered is optimal or not. This policy has been adopted by some countries like the United Kingdom. In their model, the authors also determine optimal water volumetric and fixed charges. The authors conclude that it may be efficient not to meter every customer and to have a dual system where the customer chooses if he should be metered or not (with unmetered customers paying higher fixed charges).

Chambouleyron (2004) combines the analysis of optimal water pricing and metering. Consumers are heterogeneous due to the variation in the numbers of household members. Four revenue collecting regimes are compared:

- Rateable Value System (no metering is installed);

- Universal Metering;

- Optimal Metering (the socially efficient number of meters is determined in a centralized fashion; the number of meters installed is the solution to a social planner's problem maximizing welfare and not the water company's profits);

- Decentralized Metering (the optimal number of meters is determined in a decentralized way by the company, which seeks to maximize profit, and in this case it coincides with the socially efficient level).

Universal metering is only advisable if metering costs are compensated by the gain in welfare from the difference between water company's cost savings and consumer surplus losses (resulting from the decrease in consumption by the consumers that were not metered under Optimal Metering but are so under Universal Metering). When the previous condition is not fulfilled the two regimes proposed by the author, Optimal Metering and Decentralized Metering, are able to determine the socially efficient number of meters (respectively in a centralized or decentralized but regulated way).

3.3.7 Efficiency of block tariffs

As mentioned above, Gysi and Loucks (1971) point out the advantages of an increasing block rate schedule combined with a summer price differential. Brill et al. (1997), on the other hand, show the inefficiency of a two-block tiered pricing policy in a balanced budget context with marginal cost above average cost and customer heterogeneity. The inefficiency stems from the reduced price in the first block which induces low demand consumers to use more water than the efficient level. Castro-Rodríguez and Delicado (2002) show how a two-part tariff can increase efficiency regarding IBT without compromising the revenues raised (a balanced budget is assumed) nor increasing global consumption. On the contrary, Loehman (2004) discards block tariffs for being inferior to "variable unit pricing", a form of nonlinear pricing where the unit price varies linearly with the quantities used[2].

Cardadeiro (2005) develops a model of optimal pricing with customer heterogeneity and claims the use of a two-block multi-part tariff may be efficient in the presence of a public health external benefit stemming from the consumption of the first few cubic meters of water, justifying the adoption of a lower price on the first block. None of these studies seems to be conclusive as to the benefit or inconvenience of adopting nonlinear water tariffs (for example, they all impose a predetermined number of blocks on the water tariff limiting the generality of the results obtained).

Elnaboulsi (2001) develops a model of optimal nonlinear pricing of water and wastewater services. He considers the issues of temporal variation, capacity constraints, scarcity and consumer heterogeneity. The author concludes that the optimal water tariff design is a two-part tariff (to recover operating/variable and fixed costs). If consumers are homogeneous a single two-part tariff should be implemented. In the presence of heterogeneous consumers a menu of two-part tariffs (with trade-offs between the fixed charge and the volumetric charge) must be implemented. Additional charges should be included in the unit

[2] See Loehman (2008) for applications of the method to real world situations.

price to reflect the scarcity value of water (in case there is a water shortage) or capacity constraints in any of the water supply and wastewater disposal facilities and transport systems. The utility should offer the consumers quantity discounts, resulting in a decreasing marginal price (not considering the additional charges).

The impact of consumer heterogeneity is an issue yet to be fully investigated in the water pricing literature. It is usually regarded by more general pricing literature as a reason to apply nonlinear pricing schedules (Wilson (1993)). Schoengold and Zilberman (2009) is an example of the ongoing discussion about the potential of tiered pricing to simultaneously achieve the goals of efficiency, cost recovery and equity when customers are heterogeneous. In chapter 4 we develop a water pricing model which explicitly takes customer heterogeneity into account.

3.4 Conclusion

This chapter reviewed the articles which present models to determine the water pricing scheme to be adopted and the water prices to be charged. After briefly pointing out some results on existing pricing schemes, the main questions addressed by the water pricing models were systematized and the major results from these studies were presented.

The most consensual result from the water pricing literature is that efficiency requires marginal cost pricing. While this may be common sense for anyone with a minimum microeconomics background, it has stirred up a lot of articles demonstrating the advantages of marginal cost pricing in relation to the widely used average cost pricing practices of many water utilities.

Although not many articles present a seasonal analysis of prices, it does not seem to be problematic to recognize that, if marginal cost has significant seasonal variations, intra-annual price changes to reflect that variation would enhance efficiency. Assuming continuously changing prices to be unfeasible, the optimal frequency of the price changes would have to be studied. Some authors do try to analyze optimal discrete approximations of price changes to continuously time-varying marginal costs. When the pricing and investment decisions are taken simultaneously and it is possible to separate peak and off-peak consumption, peak-load pricing increases welfare.

A similar problem is that of reflecting in each customer's water bill the specificity of the costs it imposes on the water utility. While the efficiency of doing so is not questioned, the information requirements may be considerable obstacles to this refinement of marginal cost pricing.

The inclusion of the opportunity cost of water in the price when facing capacity constraints has been the subject of many studies, which besides deriving the optimal prices for water also obtain the optimal timing for the expansion of the water supply system. It is consensual that marginal cost tends to rise as the water supply system approaches its capacity limit. If a marginal cost pricing mechanism is in place, the actual water bought by customers may signal the value they attribute to further capacity expansions by revealing their willingness to pay for additional units of water.

Pure scarcity of the resource has become a concern only in more recent studies, reflecting the shift from the engineering perspective of increasing supply to satisfy demand to the economic perspective of also managing demand through pricing to efficiently allocate the existing quantity of water supply.

Only a few studies have focused on the question of whether it is optimal to meter every customer, but they are unanimous in saying that, at least, there are conditions in which leaving some connections unmetered may be efficient.

It is also accepted that pure marginal cost pricing may not be feasible or even desirable because of fairness, financial, political or legal reasons. Those concerned with fairness worry that marginal cost pricing could impose an undue burden on the poorest. In situations where the marginal cost falls below average cost, the revenue generated by marginal cost pricing may not be enough to recover the costs leading to financial losses by the water company. On the other hand, if marginal costs rise above average costs, excessive profits made through monopoly supply of what is perceived to be an essential good may not be acceptable to the public opinion or by legal standards. This raises the question of aiming at efficiency while respecting a revenue requirement. The most common ways of combining these two objectives are through the use of two-part tariffs, adjusting the fixed charge to meet the revenue requirement, or through second-best pricing, collecting the necessary extra revenue where it can be done more efficiently, that is to say, from customers with less elastic demands. These constrained versions of marginal cost pricing would still be preferable to other pricing schemes. It is not determined if the best way to do it is through two-part tariffs or some other pricing mechanism. The role of block rate pricing, increasingly more frequent in actual pricing practices, is yet to be fully investigated. In chapter 4 we investigate whether block rates can be derived from efficiency arguments, taking into account customer heterogeneity and scarcity concerns.

Chapter 4

Pricing for Scarcity

4.1 Introduction

In many areas where water is not abundant, water pricing schedules contain significant nonlinearities. When adequate distribution networks exist, utilities tend to be local natural monopolies, consumers cannot choose multiple connections and resale is tricky. Thus it is easy, and often politically expedient, for utilities to undertake extensive price discrimination, both for distinct types of consumers (residential, industrial, agricultural, and so on) and for different levels of consumption within each consumer type. Many utilities use two-part tariffs, with fixed meter charges and a constant unit price, or multipart tariffs, which combine fixed charges and increasing or, less often, decreasing blocks. Occasionally, seasonal price variations are employed to reflect changes in water availability throughout the year. Less common is the imposition of a scarcity surcharge during drought periods, regardless of the season. In extreme droughts water rationing is generally preferred.

Chapter 1 presented some relevant characteristics of existing water tariffs, focusing on the Portuguese case. As expected, tariffs are usually composed by both a meter charge and a volumetric price, but the latter almost always consists of increasing block tariffs (IBT). More surprisingly, considering the well-known significant seasonal differences in water availability in the country, seasonal surcharges or seasonal price variations are not common in Portuguese water tariffs. Moreover, the few that do exist seem to be uncorrelated with regional characteristics in terms of seasonal water scarcity. It was also emphasized that many utilities incorporate a number of further complications in their water rate calculations, enabling us to say that complexity is definitely the prevailing feature of water tariffs in Portugal. For other countries, the trend towards increasing blocks is also present, as noted in several publications.

It seems that the reasons why most water managers continue to defend increasing blocks are their ability to benefit smaller users and their potential role in signalling scarcity. Although, in the presence of water scarcity, the true cost of water increases due to the emergence of a scarcity cost, it is unclear whether increasing block tariffs are the best way to make consumers understand and respond to water scarcity situations, especially when the resulting tariffs are very complex.

In contrast, most results found in the literature on efficient tariff design do not generally recommend increasing price schedules. Only part of the abundant literature on water pricing provides efficiency results, since most studies either compare the properties of different possible price schemes, estimate water demand, or point out the difficulties in implementing more efficient pricing rules. Chapter 3 summarized the main efficiency results, indicating justifications for increasing block rates whenever they appeared, none of which was directly related to scarcity.

Current analysis of this issue is specially relevant considering that the Water Framework Directive requires that by 2010 (art.9, n.1) pricing policies in the European Union's member states not only recover the costs of the resource (including enviromental and scarcity costs) but also provide adequate incentives for consumers to use water efficiently, contributing to the attainment of environmental quality targets. In particular, the problem of water scarcity is now recognized by the European Commission as an increasingly relevant one in the face of the increased frequency of extreme climate events that may occur because of climate change, as can be seen in a recent Communication that was issued on the topic (EC (2007*a*)).

This chapter proposes different models of efficient and second-best nonlinear prices under scarcity constraints, and concludes that, when both demand and costs respond to climate factors, increasing marginal prices may come about as a combined result of scarcity and customer heterogeneity under specific conditions, even if nonlinear pricing is a consequence of customer heterogeneity and not of water scarcity. Finally, we use a dynamic model to analyze the simultaneous decision on pricing and investment by a public utility and to investigate the effect that rising water scarcity, brought about for instance by global warming, can have on the steady-state amount of capital invested in water storage and supply infrastructures, and conclude that some results are similar to the ones from the previous static models.

4.2 Existing water tariffs

In 2005, the Portuguese National Water Institute (INAG) released results for the National Survey on Water and Wastewaster Systems for 2002 (recently updated for 2005). While previous surveys had focused only on the water and sewage infrastructures, this one began a systematic gathering of economic information. The INSAAR database contained at the time of our study economic data on the management model followed by water utilities, on investments for the period 1987-2005, and on costs, revenues, prices and quantities of water delivered (to customers or to other water utilities) for the years 1998, 2000, 2002 and 2005[1]. This section recalls the description of economic data from chapter 1 for the year 2005, focusing on the domestic water supply component[2].

The data indicated that 97.5% of water supply tariffs in Portugal are composed of a fixed charge and a volumetric rate. The fixed charge is dependent on the diameter of the pipe. All the 278 water utilities responsible for public water supply at the municipal level and which provided information on tariffs have volumetric rates in their tariffs. Moreover, all but three of the them apply IBT (a few self-supplying organizations and tourist resorts also practice flat rate volumetric prices). The average number of blocks is 5, but it can be as high as thirty in some extreme cases. The majority of utilities using block tariffs charges the volume within each block. Nevertheless, 16.5% of them use a different way to calculate the final tariff, by charging all volume at the price of the last block reached by metered consumption in the period[3]. This causes the marginal price faced by the consumer

[1] Updates have already been released for the years 2006 and 2007.

[2] Because the INSAAR database suffers from a strong presence of missing values, additional data has been requested by the authors directly to the water utilities to fill in the information gaps. The statistics reported in this document already reflect such data collection and improvement.

[3] An additional 1.4% combine both calculation procedures in the tariff schedule applying one or the

to have significant peaks at the block limits. In this pricing system, the first cubic meter within a block can cost a consumer several times the price of the previous and the next unit, something that will hardly be clear to the average consumer from the information in the water bill.

The popularity of increasing block tariffs is not a Portuguese peculiarity. Hoffmann, Worthington and Higgs (2006) mention “the trend in most OECD economies towards metering, increasing block prices and reduced subsidies for residential water supply”, as reported by Dalhuisen, Groot and Nijkamp (2001) to the European Commission in 2001. The OECD itself not only reports the growing use of IBT by stating that “there is evidence that the use of such tariffs [IBT] is increasing” (OECD (2003*a*)), but also seems to support their use by saying that “there seem to be clear potential benefits from increasing block tariff structure” (OECD (2003*a*)). Bartoszczuk and Nakamori (2004) point out that “the strong tradition of low tariffs for households and increasing block rates is present in Belgium, Italy, Greece, Portugal, Spain and US”. With the Belgian exception, we find very similar climate conditions in these countries (or parts of them, given the size of the US). The use of IBT in these and other countries is also well documented in several OECD reports (OECD (1999*a*), OECD (1999*b*), OECD (1999*c*), OECD (2003*b*), OECD (2003*a*), OECD (2006) and OECD (2009)). One of the advantages of IBT, pointed out by several authors and also in the OECD reports, is related with affordability for poorer households. Nonetheless, we noted in chapter 1 that in Portugal water expenses fall below 1% of average disposable income (Roseta-Palma et al. (2006)). Furthermore, the affordability argument cannot explain the use of a large number of blocks.

One feature we would expect to see in Portuguese water tariffs given the variable weather conditions, which include significant seasonal weather differences, namely in rainfall, and the existence of drought-prone regions, is seasonal surcharges. However, chapter 1 showed that no more than 3% of water utilities use such tools in their water tariffs. Moreover, their location seems to be unrelated to the water availability problems in the country, with most of them being located in the wetter regions of the coastal northwest of Portugal. The few seasonal surcharges we do find are in place during the summer months

other according to the block of consumption reached.

and typically raise the price of the higher blocks between 30%-50%.

It is clear that simplicity is not a prevalent feature of Portuguese water tariffs. The calculation process of the IBT (volume charged within each block or at the price of the last block) can be mixed in some utilities, depending on the consumption block. Tariffs can combine blocks with flat (nonvolumetric) fees within some blocks with volumetric rates for others. Specific formulas are sometimes applied within the blocks to find the unit price. Water availability charges that are fixed within each block, but variable among blocks, are sometimes levied and added to the price. Some utilities practice social tariffs for disadvantaged households or, apart from the usual tariff differentiation by customer class, propose special contracts with different prices to various types of specific consumers (from farmers, factories or services to schools, sporting clubs or nonprofit organizations, to name a few). Furthermore, additional complications can be found in wastewater price schedules.

Finally, we noted that the 84% value for the national cost recovery level for water supply falls below 100% (considering only financial costs), and the situation is even worse for wastewater drainage and treatment services with a value of 50% (INAG/MAOTDR (2009)). This can be explained by the fact that some utilities do not charge for wastewater at all, while others make the payment dependent of variables such as apartment area; number of inhabitants/beds/rooms, real estate value of the house or building or taxable income. The majority of wastewater utilities levy at least some of their charges based on water consumption levels, so that both payments are part of the water bill.

4.3 Scarcity in a simple model

A simple view of the main aspects of efficiency in water prices is presented by Griffin (2001) and Griffin (2006). His model includes three pricing components: the volumetric (ie. per unit) price, the constant meter charge and the one-off connection charge. The latter is meant to reflect network expansion costs and will not be considered in our model.[4]

[4] Access to water supply networks is nearly universal in Portugal by now, with connection rates reaching 92% in mainland Portugal, 99% in the Azores and 97% in Madeira (INAG/MAOTDR (2009); APA/MAOTDR (2008)) (and virtually 100% in urban areas).

We focus on the volumetric part of the tariff, not taking into account the two-part tariff case[5]. On the other hand, he assumes a single volumetric price and does not allow for more general nonlinear prices, as neither consumer heterogeneity nor purchase size cost dependency are taken into account. In fact, Griffin (2001) stresses "the inefficiencies of block rate water pricing" (pp. 1339 and 1342).

A static model for different (identified) consumer groups, with a scarcity constraint, shows that the marginal cost pricing rule still holds. Define $B_j(w_j)$ as the increasing and concave monetized benefit of water consumption for consumer group j, with $j = 1, ..., J$ and $C(w)$ as the (convex) water supply costs[6], which depend on the total water supplied, ie. $w = \sum_{j=1}^{J} w_j$. Water availability is limited, with the maximum amount denoted as W. The welfare maximization problem is

$$\begin{gathered} \underset{\{w_j\}}{Max} \quad \sum_{j=1}^{J} B_j(w_j) - C(w) \\ s.t. \sum_{j=1}^{J} w_j \leq W \end{gathered} \tag{4.1}$$

resulting in first order conditions[7]

$$\frac{dB_j}{dw_j} = \frac{dC}{dw} + \mu \qquad \forall_j \tag{4.2}$$

$$\sum_{j=1}^{J} w_j \leq W, \quad \mu \geq 0, \quad \mu(W - \sum_{j=1}^{J} w_j) = 0 \tag{4.3}$$

where μ is the Lagrangean multiplier and it is assumed that all w_j are positive (every consumer requires a minimum amount of water). The efficiency result, expressed in equation (4.2), indicates that the marginal benefit of water consumption should be equal to marginal costs (including scarcity costs if the constraint is binding). Also, the marginal benefit needs to be the same across consumers, since marginal cost is the same. Finally,

[5] We assume that the fixed charge is calculated so as to cover exactly the fixed costs of the water supply activity, which is a situation similar to what is recognized as legally admissible in Portugal, since the publication of Law N. 12/2008 of February 26 (Legislation for the Protection of the Customers of Essential Public Services) (AR (2008)).

[6] We do not explicitly consider fixed costs for simplicity, because they do not change the conclusions.

[7] There are no cross effects in demand, ie. $\frac{dB_j}{dw_i} = 0$ for $i \neq j$.

with a unit price p_j the benefit maximization problem for each consumer is

$$\underset{w_j}{Max} \quad B_j(w_j) - p_j w_j \tag{4.4}$$

$$\Leftrightarrow \quad \frac{dB_j}{dw_j} = p_j \tag{4.5}$$

so that the efficient unit price must be the same for all consumers and is given by

$$p = \frac{dC}{dw} + \mu \tag{4.6}$$

as in Griffin (2006).[8] The lower the W the tighter the constraint, meaning that price should rise to reflect increasing scarcity. However, this rule does not ensure that the water utility's budget is balanced, namely if there are fixed costs or if marginal cost is not constant. Although a fixed meter component could be adjusted to reflect such concerns, for the aforementioned reasons we disregard this possibility and the second-best pricing rule is obtained by imposing a breakeven constraint such as (4.7) on problem (4.1). This is known as Ramsey pricing. Note that $p_j(w_j)$ is now the inverted demand of consumer j.

$$\sum_{j=1}^{J} p_j(w_j)w_j - C(w) = 0 \tag{4.7}$$

Using equation (4.5), the welfare maximizing prices will now be given by

$$\frac{p_j - \left(\frac{dC}{dw} + \frac{\mu}{1+\lambda}\right)}{p_j} = \frac{\lambda}{1+\lambda} \frac{1}{\xi_j\left(w_j^*\right)} \tag{4.8}$$

where ξ_j is the absolute value of the price elasticity of j's demand and λ is the Lagrange multiplier of (4.7). This is a version of the so-called Inverse Elasticity Rule, which states that the mark-up of prices over marginal cost will be inversely related to the demand elasticity, so that consumers with lower demand elasticities will pay higher prices and vice-versa. The only new term is $\frac{\mu}{1+\lambda}$, which reflects the scarcity cost. It adds to the price faced by the consumer the opportunity cost of using a scarce resource, but it does not affect the shape of the price schedule. Nonlinear prices may arise in this model because

[8] The same result can be obtained with the more complicated pricing formula from Griffin (2001). In that case the bill paid by each consumer is given by $Bill_j = M + p(w_j - \overline{w})$, where M is the meter charge and $\overline{w}$ is a budget-balancing parameter.

of heterogeneity in the consumers' preferences (different price-elasticities), not because of scarcity. Nonlinear prices would be increasing if the absolute value of price-elasticities decrease with higher optimal consumption choices and decreasing otherwise. It should be noted that if the scarcity cost is defined as a tax which the supplier collects but does not keep, along the lines of what is already done in some European countries, the model will have to be changed accordingly. This is particularly important when several suppliers share available water, since none of them will adequately provide for external scarcity costs.

4.4 Scarcity with a distribution of consumer types

In this section a more complete model is presented, explicitly characterizing demand behavior through the definition of a continuum of consumer types. Model development is based on Brown and Sibley (1986) as well as Elnaboulsi (2001). A new parameter, θ, is introduced to reflect differences in consumer tastes, which can encompass a number of variables, including income, family size, or housing. A consumer with tastes given by θ will now enjoy net benefits of $B(w, \theta) - P(w)$, where $P(w)$ is the total payment for water consumption. It is assumed that $B(0, \theta) = 0$ and that higher values of θ imply higher consumption benefits ($\frac{\partial B}{\partial \theta} > 0$, $\frac{\partial^2 B}{\partial \theta \partial w} > 0$). The distribution of θ throughout the consumer population is described by a distribution funtion $G(\theta)$ and the associated density function $g(\theta)$. Maximum and minimum values for the taste parameter are represented by $\overline{\theta}$ and $\underline{\theta}$, respectively, so that $G(\overline{\theta}) = 1$ and $G(\underline{\theta}) = 0$.

The first order condition of each consumer's net benefit maximization is

$$\frac{\partial B(w, \theta)}{\partial w} = \frac{dP}{dw} \equiv p_m \tag{4.9}$$

which is similar to condition (4.5) except the right-hand side represents the slope of the total payment function, i.e. the marginal price p_m. The only restriction to the shape of $P(w)$ is that, if concave, it must be less so than the benefit function to ensure that the decision is indeed a maximizing one. Using the consumer's choice, $w(\theta)$, the value function is

$$V(\theta) = B(w(\theta), \theta) - P(w(\theta)) \tag{4.10}$$

To find the properties of the optimal payment function with a scarcity restriction, or rather the second best function given the break-even constraint, the following problem can be solved

$$\begin{array}{ll} \underset{w(\theta)}{Max} & \int_{\underline{\theta}}^{\overline{\theta}} V(\theta)g(\theta)d\theta + \int_{\underline{\theta}}^{\overline{\theta}} \left[P\left(w(\theta)\right) - C(w(\theta))\right]g(\theta)d\theta \\ s.t. & \begin{array}{c} \int_{\underline{\theta}}^{\overline{\theta}} \left[P\left(w(\theta)\right) - C(w(\theta))\right]g(\theta)d\theta = 0 \\ \int_{\underline{\theta}}^{\overline{\theta}} w(\theta)g(\theta)d\theta \leq W \end{array} \end{array} \tag{4.11}$$

where the first component of the objective function represents consumer surplus aggregating all consumer types, and the second component is profit. Some manipulations yield a more tractable version of the problem. Substituing $P\left(w\left(\theta\right)\right)$ using equation (4.10), noting that $G(\theta) - 1 = \int g(\theta)d\theta$ and using the envelope theorem to see that $\frac{\partial V}{\partial \theta} = \frac{\partial B}{\partial \theta}$, consumer surplus can be rewritten using integration by parts

$$\int_{\underline{\theta}}^{\overline{\theta}} V(\theta)g(\theta)d\theta = V(\underline{\theta}) + \int_{\underline{\theta}}^{\overline{\theta}} \frac{\partial B}{\partial \theta}(1 - G(\theta))d\theta \tag{4.12}$$

and the Lagrangean that must be maximized is

$$\begin{aligned} \mathcal{L} &= V(\underline{\theta}) + \int_{\underline{\theta}}^{\overline{\theta}} \frac{\partial B}{\partial \theta}(1 - G(\theta))d\theta + (1+\lambda)\int_{\underline{\theta}}^{\overline{\theta}} \left(B\left(w\left(\theta\right),\theta\right) - V(\theta) - C(w(\theta))\right)g(\theta)d\theta \\ &\quad +\mu\left(W - \int_{\underline{\theta}}^{\overline{\theta}} w(\theta)g(\theta)d\theta\right) \qquad (4.13) \\ &= -\lambda V(\underline{\theta}) + \int_{\underline{\theta}}^{\overline{\theta}} (1+\lambda)\left(B\left(w\left(\theta\right),\theta\right) - C(w(\theta))\right)g(\theta) - \lambda\frac{\partial B}{\partial \theta}(1 - G(\theta))d\theta \\ &\quad +\mu\left(W - \int_{\underline{\theta}}^{\overline{\theta}} w(\theta)g(\theta)d\theta\right) \qquad (4.14) \end{aligned}$$

For the case where $V(\underline{\theta}) = 0$, which is the most relevant, the consumer with the lowest taste parameter value has no net benefit and the first order condition for each θ is

$$\begin{aligned}\frac{\partial \mathcal{L}}{\partial w(\theta)} &= 0 \qquad (4.15)\\ &= (1+\lambda)\left(\frac{\partial B}{\partial w}-\frac{\partial C}{\partial w}\right)g(\theta)-\lambda\frac{\partial^2 B}{\partial w \partial \theta}(1-G(\theta))-\mu g(\theta)=0\end{aligned}$$

Using equation (4.9), a mark-up condition similar to the one from the previous model (equation (4.8)) can be derived:

$$\frac{p_m-\left(\frac{\partial C}{\partial w}+\frac{\mu}{1+\lambda}\right)}{p_m}=\frac{\lambda}{1+\lambda}\frac{1}{\xi(w,\theta)} \qquad (4.16)$$

where $\xi(w,\theta)$ represents the absolute value of the price-elasticity of demand in each incremental market (see Appendix A). As expected, the same conclusions as in the discrete case apply to this model regarding the role of customer heterogeneity (here represented by different θ) in generating nonlinear prices, while the scarcity cost does not affect the price schedule's shape, but only its level.

4.5 Scarcity in demand, cost and availability

The previous sections have shown that scarcity, represented as a quantity constraint, has a direct effect that can be seen as an increase in real marginal cost, so that even when coupled with a budget balancing constraint it cannot in itself explain a preference for increasing rates. In order to evaluate other effects of scarcity in a more general sense, this section introduces into the previous models exogenous weather factors, ϕ, which affect water availability as well as consumer benefits and supply costs. It is assumed that a higher value of ϕ means hotter and drier weather, implying that $\frac{\partial B_j}{\partial \phi}>0$, $\frac{\partial^2 B_j}{\partial w_j \partial \phi}>0$ (water demand increases, for example due to irrigation or swimming pools), $\frac{\partial C}{\partial \phi}>0$, $\frac{\partial^2 C}{\partial w \partial \phi}>0$ (supply costs are higher due to extra pumping or treatment costs), and $\frac{dW}{d\phi}<0$ (less available water).

Introducing these factors into the models from sections 4.3 and 4.4 does not change the fundamental result for the second-best price schedule, expressed by the inverse elasticity rule. The first-order conditions for the discrete and the continuous cases, regarding customer heterogeneity, become:

$$\frac{p_j - \left[\frac{\partial C(w^*,\phi)}{\partial w^*} + \frac{\mu}{1+\lambda}\right]}{p_j} = \frac{\lambda}{1+\lambda}\frac{1}{\xi_j\left(w_j^*,\phi\right)} \tag{4.17}$$

$$\frac{p_m - \left(\frac{\partial C(w^*,\phi)}{\partial w^*} + \frac{\mu}{1+\lambda}\right)}{p_m} = \frac{\lambda}{1+\lambda}\frac{1}{\xi(w^*,\theta,\phi)} \tag{4.18}$$

Nonlinear pricing is still a consequence of customer heterogeneity and not of scarcity considerations. However, the shape of the resulting price schedule may now be affected by the influence of the exogenous weather factor on the price-elasticities of water demand for the different consumer types.

4.5.1 Impact of scarcity on the shape of the price schedule

As noted earlier, the marginal unit price and the mark-up for each consumer type or market increment depend inversely on its price-elasticity of demand. Nonlinear prices would be increasing if the absolute value of price-elasticities decrease with higher optimal consumption choices and decreasing otherwise. We can investigate the conditions under which the resulting price schedule is increasing, constant or decreasing and how they are affected by the weather parameter. The partial derivatives of the elasticity with respect to the optimal level of water consumption are, for the discrete and the continuous model, respectively:

$$\frac{\partial \xi_j\left(w_j^*,\phi\right)}{\partial w_j^*} = -\frac{\left[\frac{\partial^2 B_j\left(w_j^*,\phi\right)}{\partial w_j^{*2}}\right]^2 w_j^* - \frac{\partial B_j\left(w_j^*,\phi\right)}{\partial w_j^*}\left[\frac{\partial^3 B_j\left(w_j^*,\phi\right)}{\partial w_j^{*3}} w_j^* + \frac{\partial^2 B_j\left(w_j^*,\phi\right)}{\partial w_j^{*2}}\right]}{\left[\frac{\partial^2 B_j\left(w_j^*,\phi\right)}{\partial w_j^{*2}} w_j^*\right]^2} \tag{4.19}$$

$$\frac{\partial \xi(w^*,\theta,\phi)}{\partial w^*} = -\frac{\left[\frac{\partial^2 B(w^*,\theta,\phi)}{\partial w^{*2}}\right]^2 w^* - \frac{\partial B(w^*,\theta,\phi)}{\partial w^*}\left[\frac{d^3 B(w^*,\theta,\phi)}{dw^{*3}} w^* + \frac{\partial^2 B(w^*,\theta,\phi)}{\partial w^{*2}}\right]}{\left[\frac{d^2 B(w^*,\theta,\phi)}{dw^{*2}} w^*\right]^2} \tag{4.20}$$

The price schedule will be increasing, constant or decreasing according to whether $\dfrac{\partial \xi}{\partial w^*}$ is negative, null or positive. The conditions for each case are described below (because the result is the same for the discrete and the continuous models we only present them once in a general form).

In order for elasticity to stay the same regardless of consumption, implying that efficient unit price will be constant, the following condition is necessary and sufficient:

$$\frac{\partial \xi(w^*, p_m)}{\partial w^*} = 0 \Leftrightarrow \frac{\frac{\partial B}{\partial w^*}\left[\frac{\partial^3 B}{\partial w^{*3}} w^* + \frac{\partial^2 B}{\partial w^{*2}}\right]}{\left[\frac{\partial^2 B}{\partial w^{*2}}\right]^2 w^*} = 1 \tag{4.21}$$

Likewise, for $\frac{\partial \xi}{\partial w^*} < 0$ the expression on the right-hand side of equation (4.21) must be smaller than 1 and for $\frac{\partial \xi}{\partial w^*} > 0$ it must be greater than 1. It can be shown that the sign of $\frac{\partial^3 B}{\partial w^{*3}}$, which reflects the curvature of the demand function, plays a very important role in determining the shape of the resulting price schedule. In particular, $\frac{\partial^3 B}{\partial w^{*3}} \leq 0$ is a sufficient condition for IBT to be efficient. Additionally, to verify the impact of the weather parameter on the price schedule we just have to differentiate the expression from (4.21) in relation to ϕ. We omit the lenghty resulting expression and present only sufficient conditions for the result to be negative, i.e., for the influence of the weather variable on the price schedule to reinforce the case for IBT.

$$\frac{\partial^3 B}{\partial w^{*3}} \leq 0 \tag{4.22}$$

$$\frac{\partial^3 B}{\partial w^{*2} \partial \phi} \geq 0 \tag{4.23}$$

$$\frac{\partial^4 B}{\partial w^{*3} \partial \phi} \leq 0 \tag{4.24}$$

Condition (4.22) means that the demand function would have to be concave. Condition (4.23) implies that the demand function's negative slope would have to be constant or to become less steep as temperature and dryness increase. Finally, condition (4.24) requires the demand function's curvature to be constant or to become more concave as temperature and dryness increase. Why do these conditions favour the adoption of IBT in hotter and drier regions or time periods? They seem to create a framework where willingness to pay for water consumption increases more with temperature in high demand consumers than in those with low demand profiles, decreasing the difference in marginal valuation of the initial consumptions and the more extravagant ones. This is consistent with the fact that low demand residential consumers have a mainly indoor water use which does not vary much with weather conditions, whereas high demand residential consumers include those with gardens to sprinkle or swimming pools to fill in the summer, therefore showing a more variable demand pattern.

High demand residential consumers are also usually associated with higher income levels (reflected in θ in our model) which means that water expenses can weigh very little on their budget. In this context, relative water demand rigidity between high and low demand users may increase, with high income and high demand users being more willing and able to afford the ever more scarce water as temperature increases. In the presence of a Ramsey pricing policy (with price levels inversely related with price-elasticities of demand) this would mean that the tariff schedule would tend towards IBT as temperature increases and a bigger share of the water utility's revenues would be generated by high demand consumers. This may be an explanation for the fact that IBT's are more frequent in countries with hotter and drier climate, as it is in Europe where we find them mainly in the Mediterranean countries. Further research in water demand estimation that explicitly takes into account both climate variables and price structures could shed some light on whether the conditions presented above actually hold.

4.5.2 Impact of scarcity on water consumption

We now evaluate the impacts of scarcity in a two-consumer version of the simplest model from section 4.3 (with and without the budget balancing constraint). The welfare maximization problem when no budget balancing constraint is imposed becomes

$$\begin{aligned} \underset{\{w_1,w_2\}}{Max} \quad & \sum_{j=1}^{2} B_j(w_j,\phi) - C(w,\phi) \\ & s.t. \sum_{j=1}^{2} w_j \leq W(\phi) \end{aligned} \tag{4.25}$$

As before, marginal benefit must be equal for both consumers, so that the marginal price must be the same, and the effects of the weather on costs and on scarcity aren't consumer-specific, so there is no scarcity related reason to use increasing marginal prices.

This may no longer be the case when a breakeven constraint is imposed on the model, resulting the inverse elasticity rule presented in equation (4.17). If both the physical and the financial constraints are binding, the first-order conditions provide a solution for $w_1^*(\phi)$,

$w_2^*(\phi)$ and $\mu^*(\phi)$, which can be used for comparative static analysis of ϕ. The main results for the case without the budget balancing constraint can be summarized as follows:

- the sign for $\frac{d\mu^*}{d\phi}$ is undetermined, but will be positive if we assume that the marginal benefit of consumption increases more with drier weather conditions than the marginal cost of water supply (excluding the opportunity cost of the resource): $\frac{\partial^2 B_j}{\partial w_j \partial \phi} > \frac{\partial^2 C}{\partial w \partial \phi}, \forall j$.

- $\frac{dw_j^*}{d\phi}$ is negative for both consumers, as expected, only in the case of homogeneous consumers. If the marginal benefit functions and the way they respond to weather conditions ($\frac{\partial^2 B_j}{\partial w_j \partial \phi}$) differ, then the sign becomes undetermined, specially for the type whose demand increases more with the increase in temperature. If the consumer types differ enough it may become efficient to have one type of consumers (those whose willingness to pay increases more with temperature increases and the resulting scarcity) increasing their water consumption during the drier periods at the cost of the water savings of the one whose marginal benefits change less. This conclusion can be interpreted in terms of high vs low demand consumer types as we have done so far or in terms of different customer classes (residential customers, farmers, factories, ...) where some customer class increases consumption during the summer months (for example, agricultural irrigation). The necessary and sufficient condition for consumer type 1 to increase its optimal consumption with temperature increases is:

$$\frac{dW}{d\phi} > \frac{\dfrac{\partial^2 B_1}{\partial w_1 \partial \phi} - \dfrac{\partial^2 B_2}{\partial w_2 \partial \phi}}{\dfrac{\partial^2 B_2}{\partial w_2^2}} \tag{4.26}$$

The conclusion is rather different for the case with Ramsey pricing. Assuming heterogeneous types, $\frac{dw_j^*}{d\phi}$ is always negative. No consumer class increases consumption in scarcity times no matter how valuable the water is to them. This is because, with Ramsey pricing, the greater willingness to pay from one consumer type will be reflected in a less elastic water demand. This is taken into account in the water utility optimization problem which assigns the group's optimal consumption a higher price (thus balancing the utility's budget with second-best efficiency). The quantity demanded by the group falls accordingly, so that in this context the higher valuation of water in a scarcity situation does not provoke higher consumption, like it did in the case without the financial constraint, where the group which valued water the most could, in some cases (through the utility's pricing decisions), "lead" the other to save water so it could consume more.

4.6 Dynamic analysis of scarcity

The previous models' inclusion of weather/scarcity impacts not only on water availability, but also on benefit and cost functions, can be carried over to a dynamic setting that enables us to study the long run effects of climate change on water resources, namely on the amount of necessary investment on water supply, treatment and storage infrastructure. We adapt a dynamic model by Brock and Dechert (1985) for the public utility pricing and investment decisions so it is consistent with the characteristics of our previous static models. We consider, that in the long-run, water scarcity can be dealt with through the combination of water demand management (through marginal cost pricing or Ramsey pricing) and investment in water infrastructure. For example, seasonal water inflow variability can be dealt with through dam construction to stabilize the amount of available water supply, thus allowing average yearly water availability to increase. Or alternative sources, other than surface water, can be explored, like groundwater pumping or seawater desalination. The main novelty in the dynamic model is the introduction of a water availability production function depending positively on capital invested in water supply infrastructure and negatively on the weather variable.

Let t denote the time period, K_t the capital invested in water withdrawal, treatment, storage and distribution infrastructure and W_t be determined by the water production function:

$$W_t = f\left(K_t, \phi_t\right) \tag{4.27}$$

where $\frac{\partial W}{\partial K} > 0$, and $\frac{\partial W}{\partial \phi} < 0$ as before.

Capital can be built upon by investment in infrastructure, I_t, and it will depreciate at rate δ, so that its evolution through time is given by:

$$\dot{K} = I - \delta K$$

Following Brock and Dechert (1985), we assume the total investment cost in period t to be given by $I_t + c(I_t)$ (price of capital is normalized to 1), where $c(I_t)$ represents installation costs and $\frac{\partial c(I_t)}{\partial I_t} > 0, \frac{\partial^2 c(I_t)}{\partial I_t^2} > 0$. Furthermore, we denote by $BL(w_t, \phi_t) = B(w_t, \phi_t) - C(w_t, \phi_t)$ the social net benefit from water consumption. The assumptions made in previous sections about the benefit and cost functions apply.

Assuming the resource constraint is binding, so that all the water made available through the water supply infrastructure is consumed, and using r as the appropriate discount rate, the dynamic optimization problem is:

$$\max \int_0^\infty e^{-rt} \{BL(f(K_t, \phi_t), \phi_t) - I_t - c(I_t)\, dt \tag{4.28}$$

$$s.t. \begin{cases} \dot{K} \equiv I - \delta K \\ K(0) = K_0, \ K(\infty) \text{ free} \end{cases} \tag{4.29}$$

resulting in the autonomous differential equation system:

$$\dot{I} = \frac{(r+\delta)\left(1 + \frac{\partial c(I)}{\partial I}\right) - \frac{\partial BL(K,\phi)}{\partial K}}{\frac{\partial^2 c(I)}{\partial I^2}} \tag{4.30}$$

$$\dot{K} = I - \delta K \tag{4.31}$$

whereby the system's steady-state can be described by:

$$\begin{cases} \dot{K} = 0 \\ \dot{I} = 0 \end{cases} \Leftrightarrow \begin{cases} I = \delta K \\ 1 + \frac{\partial c(I)}{\partial I} = \frac{\frac{\partial BL(K,\phi)}{\partial K}}{r+\delta} \end{cases} \tag{4.32}$$

In a steady-state situation, gross investment merely replaces depreciated capital, and the cost of an additional unit of investment must be equal to the capitalized value of the marginal benefit. It can be shown that the steady state is a saddle point. For every level of current capital, only one investment decision will be located on the stable branches, giving the solution for the investment variable in every time period. If we start from a lower value for K than its steady-state value, than investment should be high initially and it should decrease gradually as we approach the steady-state. If we start from a level of

K above the steady-state value, than the investment should be lower than the depreciated capital to allow for the amount of capital invested to decrease. Investment levels should recover as the steady-state is approached.

It should be noted that, since the ϕ value to be considered in the long-run investment decisions should in principle be an average expected value, unexpected and temporary fluctuations in ϕ should not change the investment decisions nor the optimal steady-state level of capital invested. We may then ask the comparative-static question of what impact will an expected permanent increase in ϕ (such as the one that would occur for Mediterranean areas in a global warming context) have. The answer depends on the sign of $\frac{d}{d\phi}\left[\frac{\partial BL(f(K,\phi),\phi)}{\partial K}\right]$, i.e., on the impact of increased temperature and water scarcity on the marginal net benefit of additional units of capital. The steady-state levels of capital and investment would rise with ϕ if $\frac{d}{d\phi}\left[\frac{\partial BL(f(K,\phi),\phi)}{\partial K}\right]$ is positive. Two conditions are sufficient for this to be the case:

$$\frac{\partial^2 B(w,\phi)}{\partial w \partial \phi} \geq \frac{\partial^2 C(w,\phi)}{\partial w \partial \phi} \tag{4.33}$$

$$\frac{\partial^2 f(K,\phi)}{\partial K \partial \phi} \geq 0 \tag{4.34}$$

Condition 4.33 is similar to the one we found in Section 4.4 for the scarcity cost to increase with temperature. This is expected given that in the dynamic model, water availability can always be increased through investment. Condition 4.34 requires the marginal productivity of capital not to decrease with water scarcity. If we reverse the signs of the inequalities we have the necessary, albeit not sufficient, conditions for optimal steady-state capital and investment levels to decrease with temperature.

Further research could combine the techniques of nonlinear pricing with optimal control to investigate the long-run properties of nonlinear prices. A description of Ramsey pricing in an isoperimetric problem is presented in Appendix B.

4.7 Conclusion

We set out to write this paper because of a puzzling question: if increasing block tariffs for water are not recommended in theoretical economic models, why are they so popular in practice? Clearly, having one block where water is charged at a low price (or even a small free allocation) can be justified by the need to ensure universal access to such a vital good. Yet the IBT schemes we found were much more complex than that. Water managers often mention that increasing rates signal scarcity and as such are a useful tool in reducing resource use. We find, after a thorough revision of the literature and an experimentation with different models, that a relatively strong conclusion stands out: the best way to allocate water when scarcity occurs is to raise its price in accordance with its true marginal cost, which includes the scarcity cost. Nonlinear pricing is a consequence of consumer heterogeneity and not of scarcity considerations.

However, the shape of the resulting price schedule may, in specific circumstances, be affected by the influence of the exogenous weather factor on the price-elasticities of the demands for the different consumer types. If high demand consumers' willingness to pay for water rises more with temperature increases relative to low demand consumers than IBT may be more appropriated in countries with hotter and drier climates. This is consistent with the fact that mediterranean European countries are often mentioned in OECD reports to make extensive use of IBT. Other results from our models are: the impact of weather on the scarcity cost depends on the impact that weather has on the marginal net benefit of water consumption; it may be efficient for some consumer types to increase their water consumption in drier periods when marginal cost pricing is followed, but that is not the case in the context of a Ramsey pricing policy. The positive association of the impact of weather on the scarcity cost and on the marginal net benefit of water consumption can be confirmed by introducing dynamic water availability explicitly into the model.

The temporal variability of supply may originate from a regular and expected seasonality or from a more uncertain inter-annual irregularity of water inflows. One possibility for extension of this work is that optimal coping strategies may be different, which can lead us to reconsider the role of capital investments like dam construction in the stabilization of water supply and in the prevention of droughts, namely when compared to demand management tools such as pricing.

There are many other avenues for further research which can now be followed. One is the combination of dynamic water variability with nonlinear pricing techniques. In order to assess the potential of nonlinear prices to promote efficiency in the use of water, to reduce overall water demand, and to recover the costs of water supply, it is also important to consider real water demand profiles. In chapter 5 we test whether the conditions under which IBT is an efficient policy for drier countries hold. The assertion that IBT are, per se, scarcity signals with the potential to influence consumer behavior even when price elasticities are very low (as they tend to be for water) could also be tested with econometric models. Finally, a comparison between the merits of nonlinear pricing and optimal two-part tariffs regarding the efficiency coupled with a budget constraint in a context of scarcity and consumer heterogeneity could be performed.

Chapter 5

Residential Water Demand in Portugal: checking for efficiency-based justifications for increasing block tariffs

5.1 Introduction

Increasing block tariffs (IBT) are often supported as a good tool for achieving the goals of equity and water conservation (Bithas (2008)). The lower prices charged for the first cubic meters of water are meant to favour the consumers with lower incomes, using water mainly for essential uses such as drinking, washing, bathing or flushing a toilet. The higher prices for the following consumption blocks are set to induce water savings from more intensive water users, usually associated with wealthier households and with nonessential uses such as sprinkling gardens or filling pools. It is thus seen as a form of cross-subsidization of the access to an essential good by the poorer through the penalization of wasteful consumptions of the richer. A third objective to be achieved through IBT is revenue neutrality (Baumann, Boland and Hanemann (1997)) because they allow the utility to break-even, while still using marginal-cost pricing for the upper blocks, in a situation of increasing marginal costs[1]. If Ramsey pricing is used, no particular block rate will necessary equal

[1] The water industry is usually seen as a natural monopoly, with large fixed costs and decreasing average costs. Nevertheless, if we consider the opportunity costs of using water resources in situations of scarcity, marginal costs will be increasing, and may in theory overcome average costs, making them increasing from that point onward.

marginal cost, but the prices for consumption units will come as close to the optimum solution as allowed by the budget-balancing restriction[2]. One last justification for IBT is the presence of a positive externality from a minimum amount of water consumption from a public health point of view, "reducing the risks of communicable diseases throughout the community" (Boland and Whittington (2000)). Cardadeiro (2005) develops the argument that, up to a level of satisfaction of basic human needs, a positive public health externality exists and derives the formal implications for an optimal water tariff, which, in his proposal, should include two increasing rate blocks.

In spite of the growing popularity of IBT both in developed countries (OECD (2003*a*), OECD (2006) and OECD (2009)) and in the developing world (Boland and Whittington (2000)) they are also subject to criticism. Sibly (2006) argues that "IBT are inferior to two-part tariffs" concerning efficiency and that equity goals could alternatively be achieved through the service charge. Boland and Whittington (2000) also show the limitations of IBT, proposing instead that a rebate be coupled with a uniform volumetric rate, for the purpose of achieving a balanced budget for the water utility. Hewitt (2000) also points out that IBT induce greater variability in the utilities' revenues, especially if a great proportion of users is consuming in the upper blocks and the variable component of the tariff is significant relative to the fixed charge.

Even the equity argument for IBT has been subject to some criticism, especially regarding its application in the developing world. The existence of shared connections and indirect purchasing of water from neighbors is pointed out by Whittington (1992) and Boland and Whittington (2000) as a reality which may lead the poor to pay a higher price for water if IBT are in place. The same argument has been used regarding households with numerous members, more frequently associated with low income families (Dahan and Nisan (2007) and Bithas (2008))[3]. Crase, O'Keefe and Burston (2007) sums up the merits

[2]IBT may result from Ramsey pricing under certain conditions, but this is not a necessity. Uniform rates or decreasing block tariffs can also be a result of a Ramsey pricing technique.

[3]See Barberán and Arbués (2009) for an example of a water tariff design proposal which takes into account the household size in order to improve equity with increasing block tariffs. The same concerns with the introduction of equity criteria in the design of residential water tariffs are reflected in the proposals of García-Valiñas (2005*a*) for two-part tariffs and Ramsey pricing and in the proposal of Diakité et al. (2009) for a nonlinear social price. Schoengold and Zilberman (2009) investigate the conditions under which tiered pricing may simultaneously achieve the goals of efficiency, cost recovery and equity.

and disadvantages of IBT while Baumann et al. (1997) presents some case studies of their application.

Hewitt (2000), p. 275 notes that "utilities are more likely to voluntarily adopt this market mimicking rate structure [IBT] if they are located in climates characterized by some combination of hot, dry, sunny, and lengthy growing season", something that is confirmed by the recent OECD publications (OECD (2003*a*)). In Europe they are more common in the Mediterranean countries like Portugal, Spain, Italy, Greece or Turkey, where the majority of the utilities adopts them[4]. This also happens in Japan and South Korea, which are located at a similar latitude. They are also common in countries like Belgium and the USA and Australia but to a less extent. In Portugal, IBT are commonly used by water utilities to price residential water use. Their presence is virtually universal, even though the tariffs are decided at the level of each of the more than 300 municipalities, as was showned in chapter 1. The National Regulating Authority for Water and Waste has included a four-block tariff design in its proposal for a tariff regime that should seek to promote efficient water pricing, as imposed by the European Water Framework Directive, approved in 2000 and translated into the new Portuguese Water Law in 2005.

After reviewing the literature on water pricing models in chapter 3, we have shown in chapter 4 that nonlinear increasing tariffs may be justified as a second-best optimum in a situation of water scarcity and budget-balancing requirements when the water utility faces heterogeneous consumers[5]. The conditions under which nonlinear increasing tariffs may be justified by efficiency reasons as a second-best solution were derived. In this chapter we aim to test whether those conditions hold in Portugal and whether the climate can be a justification for the adoption of IBT. The answer to this question depends on the characteristics of the water demand function, namely the behavior of its price-elasticity. Therefore, we provide empirical estimations for residential water demand.

[4] See OECD (2003*a*), pp. 72-73, table 3.4, OECD (2006), pp. 32-33, table 5, and OECD (2009), pp. 100-101, annex 3.A2.

[5] A two-part tariff could be a first-best optimum, but its efficiency may be limited when the flexibility to use the fixed charge to balance the utilities' budgets is restricted. This is the case in Portugal, where Law 12/2008 (AR (2008)) implies that charging a fixed fee must be reasonably justified. This has been interpreted as a need to associate the revenues from the fixed charge with the fixed costs of the service, which, if coupled with marginal cost pricing, may be insufficient for a balanced budget if marginal costs are not constant.

Households can be seen as heterogeneous consumers with different characteristics and preferences. For example, the indoor water demand has been proven to differ from the outdoor/sprinkling water demand[6]. The behavior of households regarding water use will therefore be different, depending on whether they live in an apartment or in a detached house with a swimming pool or a garden. Families also differ in the amount of water-using appliances[7] or water saving devices[8] they have at home, in the number of persons in the household or in their income. While the former are characteristics which can be translated into discrete variables, the latter varies in a continuous fashion. Although discrete customer heterogeneity may also be interpreted in association with the different customer classes (residential, commercial, industrial, agricultural), we will focus on residential water demand, for which there is better available data.

Not only is water demand estimation important to allow us to test IBT efficiency conditions, but it is also valuable in itself to water managers, as growing scarcity shifts the focus from supply increasing policies to demand management tools like water pricing[9]. Knowing consumers' behavior is essential for the implementation of such demand side management policies (Agthe, Billings and Buras (2003)). It is thus "desirable to estimate water demand" given the "serious role that water demand plays in scarcity, policy and project analysis, markets and pricing" (Griffin (2006), p.273). In the words of Renzetti (2002), "for the person who is reading this book on a hot, sunny day, there is little need to explain the importance of water and the value of understanding the relationship between water use and economic influences" (ibid., p.1) (he then proceeds to present some

[6]Several studies find that price-elasticity of water demand is lower for indoor than for outdoor water uses, for example: -0.23 (indoor) -1.6 to -0.7 (outdoor) (Howe and Jr (1967)); -0.305 (indoor) and -1.38 (outdoor) (Danielson (1979)); -0.07 (indoor) and -0.68 (outdoor) (Mansur and Olmstead (2007)).

[7]Batchelor (1975) and Ford and Ziegler (1981) incorporate the existence and number of water using appliances in their estimations of residential water demand at the household level, while Garcia and Reynaud (2004), Nauges and Reynaud (2001) and Nauges and Thomas (2000) are examples of the incorporation of these kind of concerns in studies with aggregate data through the use of variables such as the % of households equiped with bathtubs or toilets.

[8]Yoo (2007) incorporates dummy variables for the existence of water saving devices in his study of residential water demand.

[9]Martin and Kulakowski (1991), for whom "knowing that there is an inverse relantionship between price and quantity demanded, and that price-elasticity of demand is inelastic rather than elastic, is all that is required" is a notable exception disagreeing with the need to obtain precise price-elasticity estimates. Nevertheless, at least one of the authors did find himself engaged in the activity he later finds unnecessary (Martin and Thomas (1986), Martin, Ingram, Lancy and Griffin (1984)).

justifications in the introduction to his book on water demand for all other readers).

We recall the efficiency conditions for IBT in section 5.2 and show that the impact the choice of functional form can have on their empirical testing in section 5.3. In section 5.4 we briefly review the residential water demand literature and section 5.5 describes the model to be estimated as well as the data. Section 5.6 explains the methodology, estimates the model and interprets the results, while in section 5.7 the proper specification tests are performed. Section 5.8 concludes.

5.2 An efficiency justification for increasing block tariffs

In this section we summarize the conditions, obtained in chapter 4, for IBT to be efficient, which we will test using Portuguese data in the current chapter. In chapter 4, we have derived the consequences for the water tariff design from using a second-best Ramsey pricing method (i.e., with a budget balancing constraint) in a situation of water scarcity and heterogeneous consumers. In particular we derived the necessary and sufficient condition for increasing, constant and decreasing nonlinear pricing to be the most efficient solution while respecting all constraints.[10] The optimal pricing rule, shown here as equation (5.1) is the classical inverse elasticity rule from Ramsey pricing, where p_m is marginal price, C is total cost and w^* is the optimal water consumption. The additional unusual component $\mu/(1+\lambda)$ results from the introduction of resource scarcity (μ is the Lagrangian multiplier of the water scarcity constraint and λ is the one from the balanced budget constraint) and reflects the opportunity cost of consuming water. Marginal water supply costs are not only a function of water consumption, but also of weather factors. They decrease with greater levels of rainfall and increase with higher temperatures (ϕ denotes hotter and drier weather conditions). Naturally, weather also affects demand. Consumer heterogeneity is represented by θ, which can stand for continuous characteristics like income or discrete features like household size or other household attributes (owning a pool,

[10] We did not include fixed costs in the model nor did they consider the possibility of using the fixed component of the tariff as a tool to guarantee that the utility breaks even. We implicitly considered that the fixed charge is calculated so as to cover exactly the fixed costs of the water supply activity, which is a situation similar to what is recognized as legally admissible in Portugal, since the publication of Law 12/2008 (AR (2008)).

living in a detached house, water using appliances, number of taps and so on).

$$\frac{p_m - \left(\frac{\partial C\left(w^*,\phi\right)}{\partial w^*} + \frac{\mu}{1+\lambda}\right)}{p_m} = \frac{\lambda}{1+\lambda}\frac{1}{\xi(w^*,\theta,\phi)} \tag{5.1}$$

In the inverse-elasticity rule, the mark-up of the price over the marginal cost is inversely correlated with the absolute value of the price-elasticity of demand ($\xi(w^*,\theta,\phi)$). This implies that higher prices must be charged to customers with more rigid demands. The tariff structure schedule will depend on the result of the following necessary and sufficient conditions[11], where B stands for the monetized benefit function:

$$\frac{\frac{\partial B}{\partial w^*}\left[\frac{\partial^3 B}{\partial w^{*3}}w^* + \frac{\partial^2 B}{\partial w^{*2}}\right]}{\left[\frac{\partial^2 B}{\partial w^{*2}}\right]^2 w^*} < 1 \Leftrightarrow \text{ Increasing block tariffs} \tag{5.2}$$

$$\frac{\frac{\partial B}{\partial w^*}\left[\frac{\partial^3 B}{\partial w^{*3}}w^* + \frac{\partial^2 B}{\partial w^{*2}}\right]}{\left[\frac{\partial^2 B}{\partial w^{*2}}\right]^2 w^*} = 1 \Leftrightarrow \text{ Uniform rates} \tag{5.3}$$

$$\frac{\frac{\partial B}{\partial w^*}\left[\frac{\partial^3 B}{\partial w^{*3}}w^* + \frac{\partial^2 B}{\partial w^{*2}}\right]}{\left[\frac{\partial^2 B}{\partial w^{*2}}\right]^2 w^*} > 1 \Leftrightarrow \text{ Decreasing block tariffs} \tag{5.4}$$

Moreover, $\frac{\partial^3 B}{\partial w^{*3}} \leq 0$ is a sufficient condition for IBT to be an efficient solution.

In chapter 4 we also derived the conditions for which the implementation of IBT is preferred for drier and hotter climates. The following set of conditions, if combined, are sufficient for IBT adoption to increase with temperature levels and lower amounts of precipitation:

$$\frac{\partial^3 B}{\partial w^{*3}} \leq 0 \Leftrightarrow \frac{\partial^2 p}{\partial w^{*2}} \leq 0 \tag{5.5}$$

$$\frac{\partial^3 B}{\partial w^{*2}\partial\phi} \geq 0 \Leftrightarrow \frac{\partial^2 p}{\partial w^*\partial\phi} \geq 0 \tag{5.6}$$

[11] In the text we refer to increasing block tariffs and decreasing block tariffs, which are "real-world" tariff schedules. Because the model from chapter 4 is derived in a continuous fashion, the conditions apply strictly to continuously increasing, uniform or decreasing nonlinear tariffs and not to block rates. Nevertheless, we use the conditions to discuss the efficiency in the increasing or decreasing nature of the "real-world" tariffs, so we choose to use the more familiar terms.

$$\frac{\partial^4 B}{\partial w^{*3}\partial \phi} \leq 0 \Leftrightarrow \frac{\partial^3 p}{\partial w^{*2}\partial \phi} \leq 0 \tag{5.7}$$

Condition (5.5) requires the water demand function to be concave. For (5.6) to apply the slope of the inverse demand function must not become more steep with temperature increases (or lower precipitation levels). Finally, (5.7) implies that the function's concavity could not decrease for higher levels of temperature and drier conditions. Taken together they denote a situation where warmer and more arid conditions have a greater impact on high levels of consumption and where the willingness to pay for water rises more significantly under these circumstances, which can be understood if we consider the association of larger users with households with greater incomes (whose water expenses weigh less on their budget) and probably houses with pools or gardens.

It should be noted that, since the verification of the above conditions at the optimum point of consumption is sufficient, they will also apply if they can be verified for the entire range of the demand function. Our econometric estimation of water demand will aim to check whether these theoretical conditions hold for the Portuguese case.

5.3 The importance of the choice of functional form

Given the findings in the previous literature, which we review in section 5.4, the water demand function can be written as:

$$w = w\left(p, \theta, \phi, z\right) \tag{5.8}$$

where w is the quantity of water demanded and p is the water price. As was previously mentioned, θ stands for income and ϕ represents weather variables such as temperature and precipitation. The vector z can include other household attibutes related to water consumption like garden or household size, the age and education of the household members or the number of water using appliances, just to name a few. $w\left(\ldots\right)$ is a parametric function which usually takes one of the functional forms we now describe.

The choice of the functional form for the equation to be estimated is one of the important decisions to be taken by the empirical analyst. Five types of functional forms are more commonly used in the estimation of residential water demand: linear, double-log;

semilogarithmic (lin-log or log-lin) and Stone-Geary. The choice of one of these options is not neutral and can have an impact on the results. Espey, Espey and Shaw (1997) and Dalhuisen, Florax, de Groot and Nijkamp (2003) include a dummy variable for loglinear specifications in their meta-analysis of the price-elasticities of water demand estimated in the literature and find positive coefficients, meaning that, *ceteris paribus*, a loglinear specification may result in a less elastic estimate. This fact is known to empirical researchers, despite the fact that it has received less attention than other aspects of the estimation process like the choice of the estimation technique (Renzetti (2002)). In this section we evaluate the consequences of different functional forms for the verification of the previous conditions for IBT.

5.3.1 Linear specification

Linear functions are common in water demand estimation, although more so in the early years than in recent studies. A linear demand function has the following form:

$$w = ap + b\theta + c\phi + dz' + f \tag{5.9}$$

where a, b, c, d and f are parameters to be estimated. The corresponding inverted demand function is:

$$p = \frac{w - (b\theta + c\phi + dz' + f)}{a} \tag{5.10}$$

With this kind of functional form, not only is the sufficient condition for IBT (condition (5.5)) automatically verified, but that is also the case for conditions (5.6) and (5.7). This was expected because linear functions impose that demand is more elastic for higher levels of price (lower consumption levels) and lower otherwise. In linear demand functions, absolute values of the price-elasticity of demand decrease with the quantity demanded, generating IBT when coupled with the inverse elasticity rule from (5.1).

5.3.2 Double-log specification

Even more popular than the linear specification is the logarithmic functional form or double-log[12]. Double-log demand specifications assume a constant price-elasticity for every price level which can be read directly from the estimated coefficient for price. The double-log functional form for water demand can be written in the following fashion:

$$\ln w = a \ln p + b \ln \theta + c \ln \phi + dz' + f \tag{5.11}$$

The corresponding inverted demand function is:

$$p = \exp \left\{ \frac{\ln w - (b \ln \theta + c \ln \phi + dz' + f)}{a} \right\} \tag{5.12}$$

Condition (5.5) is verified in this case if and only if $a \geq 1$, but this implies a nonnegative slope for the demand function, which would be an unrealistic assumption. Therefore, unlike in the linear case, (5.5) will never be verified for a reasonable demand function with a double-log functional form. However, this does not mean that double-log specifications exclude the possibility of IBT, since we can use the necessary and sufficient condition (5.2) to determine the shape of the price schedule. Finally, the verification of conditions (5.6) and (5.7) would simply require a positive coefficient for ϕ.

5.3.3 Semilogarithmic specification (log-lin)

The semilogarithmic specification is much less frequent in the residential water demand estimation literature, but from Andrews and Gibbs (1975) to Arbués and Villanúa (2006), we do find some studies which include estimations with this functional form. The log-lin specification for water demand is:

$$\ln w = ap + b\theta + c\phi + dz' + f \tag{5.13}$$

The corresponding inverted water demand function is:

$$p = \frac{\ln w - (b\theta + c\phi + dz' + f)}{a} \tag{5.14}$$

[12] This can be seen from the two meta analysis performed by Espey et al. (1997) and Dalhuisen et al. (2003) where the majority of the studies used logarithmic functional forms.

The verification of (5.5) for a log-lin specification would only occur if and only if $a \geq 0$, which is a situation similar to the one found for the double-log form, i.e., the verification of the sufficient condition for IBT would imply a nondecreasing slope for the demand function, and can thus be discarded as unrealistic[13]. Although conditions (5.6) and (5.7) are automatically verified for the log-lin form, the positive effect of temperature on the adoption of IBT would be proven from the simultaneous verification of all three conditions, which is impossible with the usual negative sloping demand function[14].

5.3.4 Semilogarithmic specification (lin-log)

The lin-log semilogarithmic specification is rare and is usually only estimated for comparison purposes together with other functional forms. Al-Qunaibet and Johnston (1985) and Mu, Whittington and Briscoe (1990) are two examples of its implementation. The lin-log functional form for water demand is:

$$w = a \ln p + b \ln \theta + c \ln \phi + dz' + f \tag{5.15}$$

The corresponding inverted water demand function is:

$$p = \exp\left\{\frac{w - (b \ln \theta + c \ln \phi + dz' + f)}{a}\right\} \tag{5.16}$$

With this functional form condition (5.5) is never verified, not even in unrealistic conditions. The inverted water demand function is always strictly convex. The other two conditions would imply a nonnegative value for c and an opposite sign for a if c is positive, but this becomes irrelevant given the first result. Although not dismissing entirely the possibility of IBT, this functional form does not enable the verification of the above sufficient conditions for IBT.

5.3.5 Stone-Geary demand function and reciprocal functions in general

The Stone-Geary demand specification is:

$$w = (1 - g)\, h + g\frac{\theta}{p} + c\phi + dz' + f \tag{5.17}$$

[13] The same qualification applies here that this is an unconclusive case and not a dismissal of IBT and that we must always check 5.2 for a definitive conclusion.

[14] Recall also the relatively more complex necessary and sufficient conditions for hotter and drier conditions to favour the adoption of IBT derived in chapter 4 .

The parameter g can be interpreted as the fixed proportion of the supernumerary income[15] spent on water. This specification was first applied to water demand estimation by Al-Qunaibet and Johnston (1985)[16]. The corresponding inverted demand function becomes:

$$p = \frac{g\theta}{w - [(1-g)\,h + c\phi + dz' + f]} \tag{5.18}$$

We can see that the Stone-Geary is a particular form of the reciprocal demand function, where $f^* = (1-g)\,h$, $a = g\theta$ and $b = 0$:

$$w = a\frac{1}{p} + b\theta + c\phi + dz' + f^* \tag{5.19}$$

In fact, the conclusions are indeed the same for both forms. Because water consumption must not be less than the subsistence level implied by $(1-a)\,b+c\phi+dz'+f$, the verification of (5.5) will only happen if and only if $a = 0$. But this would mean that water consumption was unresponsive to price and income, contradicting economic theory and a great deal of accumulated empirical evidence. Thus the estimation of a significative Stone-Geary functional form (or any kind of reciprocal form), if considered superior to other functional forms by the relevant statistical tests, implies that we can not prove the sufficient condition for IBT.[17]

5.3.6 Summary of implications of the choice of functional form on elasticities of demand

We have shown that the choice of functional form can have a significant impact on the conclusions about which tariff schedule design is more adequate when facing water scarcity and budget balancing restrictions by looking at the sufficient conditions derived in chapter 4 about the shape of the demand function. Summing up, so far we have seen that while

[15] Supernumerary income is defined as the income remaining after the minimum amounts of water and all other goods have been purchased (Martínez-Espiñeira and Nauges (2004)). This minimum amounts are unresponsive to the respective price and are usually termed subsistence levels. The simplified version of (5.17) results from assuming a zero subsistence level for the other goods. See Gaudin, Griffin and Sickles (2001) or Martínez-Espiñeira and Nauges (2004) for more details.

[16] García-Valiñas, Nauges and Reynaud (2009) and Schleich (2009) are examples of recent applications.

[17] (5.6) would be verified if $c \leq 0$, which is unrealistic, while (5.7) implies that a and c must have opposite signs or that both should be null.

for the linear functional form the conditions for IBT are automatically verified and hotter and drier climatic conditions favour the adoption of IBT[18], for the other usual functional forms, we must resort to (5.2) to know with certainty what would be the most efficient tariff schedule.

Nevertheless, from the inverse elasticity rule we know that a necessary and sufficient condition for IBT is that demand becomes less price-elastic with higher levels of water consumption. We can look directly at the influence of the assumptions imposed by each functional form on the behavior of the price-elasticity of demand. We review these consequences in this section. Tables 5.1 and 5.2 present the price and income-elasticities for the functional forms described above. We can see from 5.1 that demand becomes less elastic (price-elasticity becomes less negative) with higher consumption for most functional forms. Only the double-log case is associated with constant elasticities (which makes up most of its appeal) and the Stone-Geary specification has an undetermined result, dependent on the actual values of the variables and the parameters associated. For all the cases except these two, under the conditions of our model, IBT will be a natural consequence of demand characteristics. The next step is to estimate the water demand and test which case fits best.

Table 5.1: Price-elasticities of demand for several functional forms

Functional form	**Price-elasticity** $\left(\xi_p = \frac{\partial w}{\partial p}\frac{p}{w}\right)$	$\frac{\partial \xi_p}{\partial w}$
Linear	$a\frac{p}{w} = 1 - \frac{(b\theta + c\phi + dz' + f)}{w}$	>0
Double-log	a	=0
Semilogarithmic (log-lin)	$ap = \ln w - (b\theta + c\phi + dz' + f)$	>0
Semilogarithmic (lin-log)	$\frac{a}{w}$	>0
Stone-Geary	$-\frac{g\theta}{wp} = -1 + \frac{[(1-g)h + c\phi + dz' + f]}{w}$	undetermined

Note:
$a < 0$
$b, c, g > 0$
$b\theta + c\phi + dz' + f > 0$
$\ln w - (b\theta + c\phi + dz' + f) > 0$

[18] Especially if the fixed charge is not allowed the flexibility of a lump sum charge when the utility is faced with the obligation to exactly breakeven, in a world of scarce water and consumers with heterogeneous preferences.

Table 5.2: Income-elasticities of demand for several functional forms

Functional form	**Income-elasticity** $\left(\xi_\theta = \frac{\partial w}{\partial \theta}\frac{\theta}{w}\right)$
Linear	$\frac{b\theta}{w}$
Double-log	b
Semilogarithmic (log-lin)	$b\theta$
Semilogarithmic (lin-log)	$\frac{b}{w}$
Stone-Geary	$\frac{g}{p} = \frac{w-[(1-g)h+c\phi+dz'+f]}{\theta}$

Note:
$a < 0$
$b, c, g > 0$
$b\theta + c\phi + dz' + f > 0$
$\ln w - \left(b\theta + c\phi + dz' + f\right) > 0$

5.4 Literature review

The field of residential water demand has been very productive in the past decades, ever since Metcalf (1926) took on the task of studying the effects of water rates on per capita water consumption. The number of published studies in the field has risen to a three digit figure, as can be seen from Appendix C. The existence of literature surveys can be very useful to guide new research or someone just trying to figure out what have we come to know about the role that price and demand-side management policies may play in promoting an efficient use of an ever scarcer resource. Earlier studies are best covered by Boland, Dziegielewski, Baumann and Optiz (1984), but other literature reviews can be found in Hanemann (1997*a*), Gómez-Ramos and Garrido-Colmenero (1998), Renzetti (2002), Arbués, García-Valiñas and Martínez-Espiñeira (2003) and Worthington and Hoffman (2008). Another, more quantitative source of information of the knowledge accumulated so far are the two meta-analysis of the determinants of price-elasticity of demand performed by Espey et al. (1997) and Dalhuisen et al. (2003). In Appendix C we provide an extensive, but not exhaustive, listing of the residential water demand studies in the literature and of their main characteristics.

Until the 1980's estimations for the USA dominated the literature, but since the 1990's and especially after the turn of the century, a great number of estimations from other parts of the world have been published, especially from Europe, although estimations from the developing world have already warranted a specific literature review by Nauges and Whittington (2008). For Portugal two previous estimations can be found in Martins and Fortunato (2005*b*) and Martins and Fortunato (2007).

The first few research efforts relied mostly on annual cross-section data for water utilities and on limited information on the water tariffs (having access to the unit price for a specific consumption amount instead of the entire rate schedule, for example). Nowadays, the improvement of information available enables the inclusion of a time-series dimension (and the study of seasonal variations, from monthly data) and the use of panel data is common. There is also a growing number of studies using household level data.

Water demand estimation differs fundamentally from other statistically supported water use studies in that a price variable is included as a determinant for water consumption. Throughout the years, marginal price has for the most part replaced average price as the specification of choice, but either because of data availability concerns or because the researcher believes that the price specification is an empirical question, due to the fact that consumers may not have full information on the rate schedule, average price specifications are still used or tested against marginal price[19]. The consideration of sewer charges when they appear coupled with the water price is consensual. When marginal price is the variable of choice and block rates are in place, the Taylor-Nordin specification, introduced in the water demand literature by Billings and Agthe (1980), is commonly used. It results from a modification by Nordin (1976) of the original proposal made by Taylor (1975) for a variable to accommodate the virtual income change resulting from the block design of the tariff. It considers a second price-related variable, the "difference" between the actual water bill and the value of the tariff, had all volume been charged at the marginal price. Griffin, Martin and Wade (1981) and Griffin and Martin (1981) were the first to point out the problem of the simultaneous determination of water demand and the price-related variables in the presence of block rates. It is since considered good practice to check for this bias in the estimation and, if present and significant, to solve it through instrumental variable techniques.

Other variables typically included as water demand determinants are the household income (or the assessed property value as a proxy in micro level studies), weather related

[19] Ruijs, Zimmermann and Berg (2008) is a recent example.

variables such as temperature and precipitation, or alternatively lawn moisture requirements or the number of rainy/dry or hot days, and the household size (especially at the micro level). The remaining variables included differ somewhat more, sometimes reflecting specific research questions. We can find variables related to the age of the household members or the house itself, to the water using appliances or the lot/garden size, population density, home ownership (Nieswiadomy (1992)), pool ownership (Dandy, Nguyen and Davies (1997)), water saving devices (Renwick and Archibald (1998) and Yoo (2007)) or even ethnic origin (Griffin and Chang (1990) and Griffin and Chang (1991)). Dummy variables in particular have been used extensively for season/month, region/city, water restrictions (Grafton and Kompas (2007)) or water conservation programs/messages (Renwick and Green (2000), Gaudin (2006) and Martínez-Espiñeira (2007)).

The functional form most widely used is the double-log specification for its convenience for the calculation of elasticities. The linear form has also been widely used, while other alternatives like the semilogarithmic or Stone-Geary approaches are rarer as we have seen in section 5.3.

The estimation technique is probably the most widely discussed issue, after the specification of the price-related variables. While earlier studies relied heavily on ordinary least squares, the endogeneity criticism soon stimulated the adoption of instrumental variable techniques (2SLS or 3SLS). Other methods have been used like maximum likelihood estimation, specific time-series techniques[20] or simultaneous equations methods, but it is the use of panel data techniques (fixed effects, random effects, GMM) that has seen the larger increase in the last decade. The use of discrete/continuous choice models in situations were block rates apply[21] merits special attention, but researchers have rarely had access to the necessarily more demanding information required to apply them in household level studies (Hewitt and Hanemann (1995), Olmstead, Hanemann and Stavins (2007), Olmstead (2009)) or with aggregate data (Martínez-Espiñeira (2003) and Diakité et al. (2009)).

[20] The work of Martínez-Espiñeira (2007) with cointegration is a recent example.

[21] Modelling the discrete choice of block and the continuous choice of the consumption level.

5.5 The model and the data

Data on water consumption and tariffs was provided by the Portuguese National Water Institute (INAG) for the years 1998, 2000, 2002 and 2005. It consists of aggregate data for the 278 municipalities in mainland Portugal. It has been combined with information on the income, weather, water quality and household characteristics respectively from the Ministry of Finance and Public Administration, the National Weather Institute (Instituto de Meteorologia, I.P.), the Regulating Authority for Water and Waste Services (ERSAR, ex-IRAR) and the National Statistics Institute (INE). Due to the presence of missing data concerning consumption levels it constitutes an unbalanced panel for the study period. The missing data problem was minimized through direct collection of additional information on consumption and tariffs from the water and wastewater utilities of each municipality.

The estimation of model 5.8 is based on the following functional form and hypothesis:

$$\begin{aligned} consumption_{it} = \; & f(mptotal_{it}, diftotal_{it}, income_{it}, prec_{it}, temp_{it}, \\ & waterqual_{it}, bathroom_i, elder_i, seasonal\_dwelling_i) + \alpha_i + \varepsilon_{it} \end{aligned} \tag{5.20}$$

$$\alpha_i \sim IID\left(0, \sigma_\alpha^2\right), \qquad \varepsilon_{it} = \varepsilon_{it-1} + v_{it}, \qquad v_{it} \sim IID\left(0, \sigma_v^2\right) \tag{5.21}$$

In 5.20, w is replaced by *consumption* and the price related variables (p) are *mptotal* and $diftotal$. θ is repesented by *income*, while the weather related variables (ϕ) are *prec* and *temp*. *waterqual*, *bathroom*, *elder* and *seasonal_dwelling* correspond to the z vector of variables in model 5.8. This simbology correspondence is established to enable the use of Stata outputs in the following sections.

The formulation of the error variable as the sum of a municipality effect (α_i) and an autoregressive component (ε_{it}) is not assumed from the outset but is instead the result of the preliminary analysis described in the next section. Tables 5.3 and 5.4[22] show the definition of the main variables used[23] and some summary statistics.

[22] The variables *waterqual*, *bathroom*, *elder* and *waterqual* are used in estimation as ratios varying from 0 to 1.

[23] Other variables were included in early larger models, but were droped due to the insignificance of the coefficients estimated or to avoid high levels of multicolinearity in the final model. Examples of variables tested and droped are average household size, % of population served by water supply and drainage systems or wastewater treatment plants, frequency of billing, educational level attained, population density, house age or % of detached houses in total buildings.

Table 5.3: Definition of variables

Variable	Definition
consumption	Average monthly water consumption (m^3/month)
mptotal	Marginal price of water supply and sewage (€/m^3)
diftotal	Variable part of the water and sewage bill - (MP*Water) (€/month)
fixedtotal	Fixed part of the water and sewage bill (€/month)
Income	Per capita available income (€10^3/person/year)
prec	Total annual precipitation (mm)
temp	Average annual temperature (^{o}C)
waterqual	% of delivered water analysis failing to comply with mandatory parameters
bathroom	% of regularly inhabited dwellings without shower or bathtub
elder	% of population with 65 or more years of age
seasonal_dwelling	% of dwellings with seasonal use

Table 5.4: Summary statistics

Variable	N	Mean	Std. Dev.	Min.	Max.
consumption	884	7.46	2.21	2.46	19.50
mptotal	871	0.62	0.39	0.05	4.59
diftotal	875	-0.73	1.24	-14.35	2.50
fixedtotal	864	2.09	1.35	0.00	10.49
Income	1112	3.48	3.27	0.67	29.80
prec	1112	877.53	435.65	205.47	2807.75
temp	1112	15.27	1.34	10.93	18.15
waterqual	1106	4.06	4.40	0.00	40.09
bathroom	1112	9.75	5.54	7.91	33.76
elder	1112	20.83	6.33	7.52	42.02
seasonal_dwelling	1112	23.98	11.13	4.54	54.10

The *consumption* dependent variable used is average monthly residential water consumption per customer[24] in cubic meters. Because virtually all water utilities adopt IBT we use the Taylor-Nordin specification with a marginal price (*mptotal*) coupled with the "difference" variable between the value of the water and sewage bill and the value it would reach had the marginal price been charged for all the volume consumed. Schefter and David (1985) point that the correct definition of the marginal price and difference variables for aggregate studies would be the average value of the household level of such variables and not their level at the average consumption level for the aggregate. However,

[24] The database has an annual periodicity, from which average monthly figures are derived.

very few studies had available the necessary information about the proportion of users in each block of the tariff structure to apply the theoretical correct definition and weight the averages of marginal price and difference, despite the fact that the Taylor-Nordin specification is widely accepted and used. Corral, Fisher and Hatch (1999) and Martínez-Espiñeira (2003) are notable exceptions. In our contacts with the water utilities, such information was explicitly asked for, but in the end less than a third were able to retrieve the information from their databases or records. Even among those whose management and billing software programs enabled the access to the % of users in each block, we found very few of them who could provide it systematically for the 4 years of study. Therefore, we join the mass of researchers using the best possible methods given the available data, when more theoretically correct ones are unpractical.

Generally, in the presence of IBT, the difference variable is nonpositive[25] and so is its expected coefficient. However, Martins and Fortunato (2007) estimates a positive coefficient and finds a justification in the fact that the difference variable includes both the effect of the block schedule (nonpositive for IBT) and the positive fixed charge. The latter, not only renders the average price decreasing for the first cubic meters of consumption but also partially cancels out the usual effect of the block schedule. In contrast, we assume fixed charges ($fixedtotal$) are made explicit in the water bill, since they are present in virtually all residential tariffs, so that we can separate them from the "difference" variable for the volumetric part of the tariff ($diftotal$).

The *income* variable chosen is disposable income per household (deducting the personal income taxes collected from the taxable personal income) in €10^3/year[26]. The available weather related variables are total annual precipitation (*prec*, in mm) and average annual temperature (*temp*, in ^{o}C). A measure of the quality of water delivered to the consumers

[25] This is the case for the Portuguese water supply tariffs. In our estimation we add the relevant charge for wastewater drainage and treatment to the price variables to come up with the prices that the consumer actually faces in the water bill. Because it is not uncommon to find fixed charges per block of consumption (fixed within the block, but varying between blocks) in wastewater tariffs, the sewage component of the "difference" variable may be positive for volumes other than the block limits even with IBT. This effect can also be seen from the tariffs for Manila, Phillipines, shown in Palencia (1988).

[26] All monetary variables are expressed in 2005 constant prices. We used the deflator for Portuguese GDP at market prices, unit Euro/ECU, supplied by AMECO – Annual Macroeconomic Database of Directorate General for Economic and Financial Affairs (DG ECFIN) of the European Commission).

(*waterqual*) is given by the % of failures to comply with mandatory quality parameters in the analysis performed by ERSAR (ex-IRAR). We expect a negative association between this variable and water consumption. Ford and Ziegler (1981) were the first to introduce a measure of perceived water quality as an explanatory factor for residential water demand. In spite of the several studies trying to estimate the willingness to pay for improved tap water quality (Whitehead (1995) and Um, Kwak and Kim (2002)) or improved service quality (Hensher, Shore and Train (2005) and Wang, Xie and Li (2008)) we found no other examples of the introduction of water quality as a regressor in water demand estimations before Piper (2003) who introduced water hardness as a measure of delivered water quality which can be perceived by the consumers. Two other recent studies use quality measures but pertaining to raw water. Reynaud, Renzetti and Villeneuve (2005) uses average biochemical oxygen demand (BOD) of raw water and Reynaud (2008) includes the share of rivers classified as bad quality within a given local community as regressors in water demand estimation.

The remaining conditioning variables, collected from INE, are the % of the population with 65 or more years of age in the municipality, % of inhabited residential dwellings without a shower or bathtub installed and the % of houses with a seasonal use. We expect negative coefficients for these variables.

The % of elderly people has been used as a determinant of water demand by Nauges and Thomas (2000), Nauges and Reynaud (2001), Martínez-Espiñeira (2002), Martínez-Espiñeira (2003) and Martins and Fortunato (2007). They all have convincingly shown that older people use less water. The results are not so clear when the variable used is average household age as is the case with Ford and Ziegler (1981) and Schleich and Hillenbrand (2009) which suggests that water savings are more related to elderly retired people than to age in general[27].

The importance of the existence of water using equipment on the amount of water demanded is recognized in many estimation studies which deal with household data through the inclusion of variables like the number of taps (Ford and Ziegler (1981) and Renwick

[27] Yoo (2007) uses the number rather than the proportion of elderly people, what explains the positive coefficient obtained.

and Archibald (1998)) or the number of bathrooms (Chicoine, Deller and Ramamurthy (1986) and Olmstead et al. (2007) are just two examples). Recently, aggregate studies have began to use their the % of houses with bathtubs and/or toilets to take this dimension into account (see, for example: Nauges and Thomas (2000), Nauges and Reynaud (2001) or Garcia and Reynaud (2004)).

Seasonality in water demand was an early concern and was considered either through the separation of indoor and outdoor/sprinkling water demands (Howe and Jr (1967)) or through the inclusion of seasonal dummy variables (Morgan (1974)). Nevertheless, its relation with a seasonal population and not only with the seasonal behavior of a stable population has failed to be considered. The exclusion of this dimension may bias the results, especially in aggregate demand studies including areas with a great importance of tourism, with a large proportion of emigrated population or with an important proportion of secondary houses owned by people living in large nearby urban centres which use the secondary house in weekends for example. This is the case in many areas of Portugal. Algarve, for example greatly increases its population in the summer with tourists from all over the country and from abroad filling up hotels and occupying rented or secondary houses, which are usually left empty for the rest of the year (a phenomenon which happens also in some other coastal areas with pleasant beaches although in a less intensive fashion). The rural villages in the inland regions also increase their population in the summer through the inflow of families with relatives who migrated to the urban centres or to foreign countries. The usual procedure of dividing total volumes of water supplied by the number of residential customers, used in aggregate studies, without consideration of this reality, where it is important, creates the usual econometric problem of relevant variables exclusion bias. The only other study known to the author which took these considerations into account was Reynaud (2008) which considered not only a dummy variable for the tourist areas but also the share of seasonal population through the inclusion of the ratio between the number of hotel rooms and camping places and the total population. He finds a positive effect of this latter variable on peak average daily residential water demand per user and surprisingly the coefficient's sign remains the same in the off-peak demand equation [28].

5.6 Methodology, estimation and results for a linear functional form

The problem of endogeneity of marginal price (or average price) and the difference variable in the presence of block rates, due to the fact that they are simultaneously determined with the volume consumed, has been acknowledged since the famous comments of Griffin et al. (1981) and Griffin and Martin (1981) on the estimations by Foster and Beattie (1979) and Billings and Agthe (1980). Special importance has been given to the existence of measurement error in the quantity variable and its influence on the block price assigned to observations close to the block limits. Billings (1982) eventually reestimated the model with the data set from Billings and Agthe (1980) while introducing instrumental variable techniques in water demand estimation to correct the bias. His approach consisted of regressing the total water bill resulting from specific consumption levels against those values for consumption and obtaining the instrumented variable for price from the slope of the total bill function and the instrumented variable for difference from its intercept for each rate schedule. This procedure, also followed by Agthe and Billings (1997), Martínez-Espiñeira (2002), Martínez-Espiñeira and Nauges (2004) and Martins and Fortunato (2007), for example, has been criticized by Deller, Chicoine and Ramamurthy (1986) for not solving the original measurement error problem, even if simultaneity in marginal price and difference is eliminated. They also point out that if the consumer is responding to the total water bill and not to the full information from the rate schedule the causality direction is inverted in the auxiliary regression. In the end, this technique is not really helpful in our case given that, with some exceptions of municipalities which did not update their tariffs in specific years, every data point is a specific tariff schedule in our database. Therefore, we adopt a procedure closer to Deller et al. (1986), Reynaud et al. (2005), Olmstead (2009) and Ruijs et al. (2008) and instrument the endogenous variables from exact information from the water bill. Namely we choose the marginal price corresponding to specific volumes of

[28] Only the latter variable is included in the final estimations for peak and off-peak demand.

consumption[29] and other characteristics relevant to the calculation of the final water bill as regressors for the auxiliary equations for $mptotal$ and $diftotal$.

$$mptotal_{it} = \beta_1 + \beta_2 privcompany_{it} + \beta_3 munservices_{it} + \beta_4 muncompany_{it} + \beta_5 m3\_5_{it} + \\ + \beta_6 m3\_10_{it} + \beta_7 m3\_15_{it} + \beta_8 calc\_tariff_{it} + \alpha_i + \varepsilon_{it} \tag{5.22}$$

$$diftotal_{it} = \gamma_1 + \gamma_2 m3\_1_{it} + \gamma_3 m3\_10_{it} + \gamma_4 m3\_20_{it} + \gamma_5 calc\_tariff_{it} + \alpha_i + \varepsilon_{it} \tag{5.23}$$

$$\alpha_i \sim IID\left(0, \sigma_\alpha^2\right), \qquad \varepsilon_{it} \sim IID\left(0, \sigma_\varepsilon^2\right) \tag{5.24}$$

Tables 5.5 and 5.6 present the definition and summary statistics of the variables used to instrument $mptotal$ and $diftotal$.[30]

Table 5.5: Definition of the variables used to instrument mptotal and diftotal

Variable	**Definition**
privcompany	dummy variable (=1 if the water supply utility is a private company)
munservices	dummy variable (=1 if the water supply utility is an autonomous municipal service)
muncompany	dummy variable (=1 if the water supply utility is a municipal company)
m3_1	Marginal price of water supply and sewage for a consumption of 1 cubic meter
m3_5	Marginal price of water supply and sewage for a consumption of 5 cubic meters
m3_10	Marginal price of water supply and sewage for a consumption of 10 cubic meters
m3_15	Marginal price of water supply and sewage for a consumption of 15 cubic meters
m3_20	Marginal price of water supply and sewage for a consumption of 20 cubic meters
calc_tariff	dummy variable (=1 if all water is charged at the price of the last block reached)

The equations (5.22) and (5.23) were estimated by a random effects model[31]. The results are presented in Figures 5.1 and 5.2

[29] The specific volumes chosen resulted from previous analysis of instrument relevance and validity performed with the Anderson, Sargan and difference in Sargan tests for the values $1m^3$, $5m^3$, $10m^3$, $15m^3$, $20m^3$, $25m^3$. Figures 5.5 and 5.6 show the results of the first two tests for the final specification.

[30] The fact that maximum values for the consecutive marginal prices do not have a monotonous increasing order in spite of the wide spread use of IBT is due to the different processes used to calculate the final tariff. Most water utilities charge each m^3 of water at the price where it belongs. However, some charge the price of the last block reached for all the volume consumed, generating high values for marginal prices at the lower block limits (a graphical representation of this effect can be seen from Monteiro and Roseta-Palma (2007)). This is the reason why $calc\_tariff$ becomes essential for the creation of instruments for $mptotal$ and $diftotal$.

[31] All estimations were performed in STATA version 9.2.

Table 5.6: Summary statistics of the variables used to instrument mptotal and diftotal

Variable	N	Mean	Std. Dev.	Min.	Max.
privcompany	1112	0.04	0.20	0.00	1.00
munservices	1112	0.14	0.35	0.00	1.00
muncompany	1112	0.02	0.15	0.00	1.00
m3_1	1090	0.33	0.19	0.00	1.69
m3_5	1091	0.35	0.16	0.00	1.80
m3_10	1091	0.53	0.24	0.00	1.99
m3_15	1091	0.75	0.45	0.00	5.17
m3_20	1091	0.96	0.48	0.00	4.82
calc_tariff	1090	0.21	0.41	0.00	1.00

Figure 5.1: Random effects regression for *mptotal*

```
Random-effects GLS regression                   Number of obs      =       871
Group variable (i): mun_number                  Number of groups   =       271

R-sq:  within  = 0.0746                         Obs per group: min =         1
       between = 0.6096                                        avg =       3.2
       overall = 0.5012                                        max =         4

Random effects u_i ~ Gaussian                   Wald chi2(7)       =    456.57
corr(u_i, X)       = 0 (assumed)                Prob > chi2        =    0.0000

------------------------------------------------------------------------------
     mptotal |      Coef.   Std. Err.      z    P>|z|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
 privcompany |   .2744924   .0651976     4.21   0.000     .1467075    .4022773
 munservices |   .2340429   .0414613     5.64   0.000     .1527803    .3153055
  muncompany |   .2767612   .0687727     4.02   0.000     .1419691    .4115533
        m3_5 |   .2332474    .090815     2.57   0.010     .0552533    .4112416
       m3_10 |   .4790264   .0780023     6.14   0.000     .3261447     .631908
       m3_15 |   .2151268   .0373536     5.76   0.000     .1419151    .2883385
 calc_tariff |   .0687644   .0295666     2.33   0.020      .010815    .1267138
       _cons |   .0493945    .033396     1.48   0.139    -.0160605    .1148495
-------------+----------------------------------------------------------------
     sigma_u |  .18935664
     sigma_e |  .20611133
         rho |  .45770915   (fraction of variance due to u_i)
------------------------------------------------------------------------------
```

Figure 5.2: Random effects regression for *diftotal*

```
Random-effects GLS regression                   Number of obs      =       875
Group variable (i): mun_number                  Number of groups   =       270

R-sq:  within  = 0.0337                         Obs per group: min =         1
       between = 0.3038                                        avg =       3.2
       overall = 0.2837                                        max =         4

Random effects u_i ~ Gaussian                   Wald chi2(4)       =    134.18
corr(u_i, X)       = 0 (assumed)                Prob > chi2        =    0.0000

------------------------------------------------------------------------------
    diftotal |      Coef.   Std. Err.      z    P>|z|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
        m3_1 |   -1.04626    .334637    -3.13   0.002    -1.702136   -.3903834
       m3_10 |  -1.060509   .2983413    -3.55   0.000    -1.645247   -.4757708
       m3_20 |   -.227879   .1258336    -1.81   0.070    -.4745084    .0187504
 calc_tariff |   .8516667   .1215123     7.01   0.000      .613507    1.089826
       _cons |   .2064288   .1411448     1.46   0.144      -.07021    .4830675
-------------+----------------------------------------------------------------
     sigma_u |  .90842123
     sigma_e |  .75101607
         rho |  .59400871   (fraction of variance due to u_i)
------------------------------------------------------------------------------
```

We implement a test of exogeneity by Davidson and MacKinnon (Davidson and MacKinnon (1993)) and adapted to a panel data context by Christopher Baum and Steven Sillman, through the *dmexogxt* procedure in Stata (Baum and Stillman (1999)), to confirm the endogeneity of *mptotal* and *diftotal* and the need to use instrumental variables. Results are presented in Figures 5.3 and 5.4. The small p-values of the test confirm the need to create instrumental variables for these two endogenous regressors. This result is confirmed by the usual Hausman test. The Hausman test statistic for the comparison of the models with and without instrumenting for *mptotal* and *diftotal* has the value of 147.11, which corresponds to a p-value of 0.0000 in a $\chi^2(8)$. The test clearly rejects the null hypothesis of exogenous regressors in the original model and the instrumenting technique is called for.

Figure 5.3: Davidson and MacKinnon test of exogeneity for *mptotal*

```
. xtivreg consumption diftotalz fixedtotal income temp prec seasonal_dwelling
bathroom elder wat
> erqual (mptotal = privcompany munservices muncompany m3_5 m3_10 m3_15
calc_tariff), fe

Fixed-effects (within) IV regression         Number of obs      =        850
Group variable: mun_number                   Number of groups   =        267

R-sq:  within  = 0.0641                      Obs per group: min =          1
       between = 0.0001                                     avg =        3.2
       overall = 0.0009                                     max =          4

                                             Wald chi2(8)       =  30904.03
corr(u_i, Xb)  = -0.3103                     Prob > chi2        =    0.0000

------------------------------------------------------------------------------
 consumption |      Coef.   Std. Err.      z    P>|z|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
     mptotal |   1.112232   1.514794     0.73   0.463     -1.85671    4.081175
   diftotalz |   .4637802   .3302104     1.40   0.160    -.1834202    1.110981
  fixedtotal |   -.083323   .1528945    -0.54   0.586    -.3829908    .2163448
      income |  -.0070346   .0789411    -0.09   0.929    -.1617562     .147687
        temp |  -.4811799   .2635089    -1.83   0.068    -.9976479     .035288
        prec |  -.0003866    .000234    -1.65   0.098    -.0008452     .000072
seasonal_d~g |  (dropped)
    bathroom |  (dropped)
       elder |  -5.488469   6.626389    -0.83   0.408    -18.47595    7.499015
   waterqual |  -.8139563   1.889873    -0.43   0.667     -4.51804    2.890128
       _cons |   16.22505   4.565677     3.55   0.000     7.276485    25.17361
-------------+----------------------------------------------------------------
     sigma_u |  2.1666914
     sigma_e |  1.2409905
         rho |  .75298253   (fraction of variance due to u_i)
------------------------------------------------------------------------------
F  test that all u_i=0:     F(266,575) =     4.72         Prob > F    = 0.0000
------------------------------------------------------------------------------
Instrumented:   mptotal
Instruments:    diftotalz fixedtotal income temp prec seasonal_dwelling
bathroom elder waterqual
                privcompany munservices muncompany m3_5 m3_10 m3_15
calc_tariff

. dmexogxt

Davidson-MacKinnon test of exogeneity:  .0622942  F( 1,574)  P-value =   .803
```

Figure 5.4: Davidson and MacKinnon test of exogeneity for *diftotal*

```
. xtivreg consumption mptotalz fixedtotal income temp prec seasonal_dwelling
bathroom elder wate
> rqual (diftotal = m3_1 m3_10 m3_20 calc_tariff), fe

Fixed-effects (within) IV regression        Number of obs      =         850
Group variable: mun_number                  Number of groups   =         267

R-sq:  within  =      .                     Obs per group: min =           1
       between = 0.1107                                    avg =         3.2
       overall = 0.1089                                    max =           4

                                            Wald chi2(8)       =  14628.74
corr(u_i, Xb)  = -0.6592                    Prob > chi2        =    0.0000

------------------------------------------------------------------------------
 consumption |      Coef.   Std. Err.      z    P>|z|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
    diftotal |   .9810227    .584656     1.68   0.093    -.1648821    2.126927
    mptotalz |    .310013   1.120028     0.28   0.782    -1.885202    2.505228
  fixedtotal |   .0827221   .1647335     0.50   0.616    -.2401497    .4055939
      income |   .0871687     .10728     0.81   0.416    -.1230963    .2974337
        temp |  -.8470755   .4475978    -1.89   0.058    -1.724351    .0302002
        prec |  -.0008211   .0003662    -2.24   0.025    -.0015388   -.0001035
seasonal_d~g |  (dropped)
    bathroom |  (dropped)
       elder |  -13.85398   10.76377    -1.29   0.198    -34.95059    7.242617
   waterqual |  -1.836498   2.825884    -0.65   0.516     -7.37513    3.702134
       _cons |   24.14597   8.133092     2.97   0.003     8.205404    40.08654
-------------+----------------------------------------------------------------
     sigma_u |  2.9482308
     sigma_e |  1.8038571
         rho |  .72761512   (fraction of variance due to u_i)
------------------------------------------------------------------------------
F  test that all u_i=0:     F(266,575) =     1.74          Prob > F    = 0.0000
------------------------------------------------------------------------------
Instrumented:   diftotal
Instruments:    mptotalz fixedtotal income temp prec seasonal_dwelling
bathroom elder waterqual
                m3_1 m3_10 m3_20 calc_tariff

. dmexogxt

Davidson-MacKinnon test of exogeneity:  32.49871  F( 1,574)  P-value =  1.9e-
08
```

The relevance and the validity of the instruments used were tested through the Anderson and Sargan tests, respectively, making use of the xtivreg2 command (Schaffer (2007)).The null hypothesis of underidentification of the former test is rejected while the null of instrument validity of the latter is not, which is a good measure of the quality of the instruments used for both $mptotal$ and $diftotal$, as can be seen in Figures 5.5 and 5.6. Difference-in-Sargan tests were performed on each separate instrument for $mptotal$ and $diftotal$ to check their individual validity as instruments. None of the tests rejected the null.

Figure 5.5: Tests of instrument relevance and validity for *mptotal*

```
. xtivreg2 consumption diftotalz fixedtotal income temp prec seasonal_dwelling bathroom
elder waterqual (mptotal = privcompany munservices muncompany m3_5 m3_10 m3_15
calc_tariff)
> , fe
Warning - singleton groups detected.  18 observation(s) not used.
Warning - collinearities detected
Vars dropped:  seasonal_dwelling bathroom

FIXED EFFECTS ESTIMATION
------------------------
Number of groups =       249                    Obs per group: min =         2
                                                               avg =       3.3
                                                               max =         4

IV (2SLS) estimation
--------------------

Estimates efficient for homoskedasticity only
Statistics consistent for homoskedasticity only

                                                      Number of obs =      832
                                                      F(  8,   575) =     0.91
                                                      Prob > F      =   0.5059
Total (centered) SS     =  946.2144463                Centered R2   =   0.0641
Total (uncentered) SS   =  946.2144463                Uncentered R2 =   0.0641
Residual SS             =  885.5329826                Root MSE      =    1.232

------------------------------------------------------------------------------
 consumption |      Coef.   Std. Err.      z    P>|z|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
     mptotal |   1.112232   1.504365     0.74   0.460     -1.83627    4.060734
   diftotalz |   .4637802   .3279369     1.41   0.157    -.1789644    1.106525
  fixedtotal |   -.083323   .1518419    -0.55   0.583    -.3809277    .2142816
      income |  -.0070346   .0783976    -0.09   0.929     -.160691    .1466218
        temp |  -.4811799   .2616947    -1.84   0.066    -.9940921    .0317323
        prec |  -.0003866   .0002324    -1.66   0.096     -.000842    .0000688
       elder |  -5.488469   6.580768    -0.83   0.404    -18.38654    7.409599
   waterqual |  -.8139563   1.876862    -0.43   0.665    -4.492539    2.864626
------------------------------------------------------------------------------
Underidentification test (Anderson canon. corr. LM statistic):          16.076
                                                   Chi-sq(7) P-val =    0.0244
------------------------------------------------------------------------------
Weak identification test (Cragg-Donald Wald F statistic):                2.305
Stock-Yogo weak ID test critical values:  5% maximal IV relative bias    19.86
                                         10% maximal IV relative bias    11.29
                                         20% maximal IV relative bias     6.73
                                         30% maximal IV relative bias     5.07
                                         10% maximal IV size             31.50
                                         15% maximal IV size             17.38
                                         20% maximal IV size             12.48
                                         25% maximal IV size              9.93
Source: Stock-Yogo (2005).  Reproduced by permission.
------------------------------------------------------------------------------
Sargan statistic (overidentification test of all instruments):           6.333
                                                   Chi-sq(6) P-val =    0.3870
------------------------------------------------------------------------------
Instrumented:         mptotal
Included instruments: diftotalz fixedtotal income temp prec elder waterqual
Excluded instruments: privcompany munservices muncompany m3_5 m3_10 m3_15
                      calc_tariff
Dropped collinear:    seasonal_dwelling bathroom
------------------------------------------------------------------------------
```

Figure 5.6: Tests of instrument relevance and validity for *diftotal*

```
. xtivreg2 consumption mptotalz fixedtotal income temp prec seasonal_dwelling bathroom
elder waterqual (diftotal = m3_1 m3_10 m3_20 calc_tariff), fe
Warning - singleton groups detected.  18 observation(s) not used.
Warning - collinearities detected
Vars dropped:  seasonal_dwelling bathroom

FIXED EFFECTS ESTIMATION
------------------------
Number of groups =       249                   Obs per group: min =         2
                                                              avg =       3.3
                                                              max =         4

IV (2SLS) estimation
--------------------

Estimates efficient for homoskedasticity only
Statistics consistent for homoskedasticity only

                                                      Number of obs =      832
                                                      F(  8,    575) =     0.68
                                                      Prob > F      =   0.7085
Total (centered) SS     =  946.2144463                Centered R2   =  -0.9773
Total (uncentered) SS   =  946.2144463                Uncentered R2 =  -0.9773
Residual SS             =  1870.992685                Root MSE      =    1.791

------------------------------------------------------------------------------
 consumption |      Coef.   Std. Err.      z    P>|z|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
    diftotal |   .9810227   .5806308     1.69   0.091    -.1569928    2.119038
    mptotalz |    .310013   1.112317     0.28   0.780    -1.870088    2.490114
  fixedtotal |   .0827221   .1635994     0.51   0.613    -.2379268     .403371
      income |   .0871687   .1065414     0.82   0.413    -.1216487     .295986
        temp |  -.8470755   .4445162    -1.91   0.057    -1.718311    .0241603
        prec |  -.0008211   .0003636    -2.26   0.024    -.0015338   -.0001084
       elder |  -13.85398   10.68966    -1.30   0.195    -34.80534    7.097372
   waterqual |  -1.836498   2.806429    -0.65   0.513    -7.336997    3.664002
------------------------------------------------------------------------------
Underidentification test (Anderson canon. corr. LM statistic):          16.368
                                                   Chi-sq(4) P-val =    0.0026
------------------------------------------------------------------------------
Weak identification test (Cragg-Donald Wald F statistic):                4.131
Stock-Yogo weak ID test critical values:  5% maximal IV relative bias    16.85
                                         10% maximal IV relative bias    10.27
                                         20% maximal IV relative bias     6.71
                                         30% maximal IV relative bias     5.34
                                         10% maximal IV size             24.58
                                         15% maximal IV size             13.96
                                         20% maximal IV size             10.26
                                         25% maximal IV size              8.31
Source: Stock-Yogo (2005).  Reproduced by permission.
------------------------------------------------------------------------------
Sargan statistic (overidentification test of all instruments):           1.877
                                                   Chi-sq(3) P-val =    0.5982
------------------------------------------------------------------------------
Instrumented:         diftotal
Included instruments: mptotalz fixedtotal income temp prec elder waterqual
Excluded instruments: m3_1 m3_10 m3_20 calc_tariff
Dropped collinear:    seasonal_dwelling bathroom
------------------------------------------------------------------------------
```

For the next steps after correcting for endogenous regressors we follow the procedure by Dalmas and Reynaud (2005) and Reynaud (2008) and start by testing the presence of specific municipal effects in the data, i.e., comparing the random effects model with pooled OLS through a Breusch-Pagan Lagrangian multiplier test for random effects. Figure 5.7 shows that the null hypothesis of no specific municipal effects is clearly rejected, supporting the two-error components model presented in (5.20).

Figure 5.7: Bresch Pagan Lagrangian multiplier test for random effects

```
. quietly xtreg consumption mptotalz diftotalz fixedtotal income temp prec
seasonal_dwelling bathroom elder waterqual, re

. xttest0

Breusch and Pagan Lagrangian multiplier test for random effects:

        consumption[mun_number,t] = Xb + u[mun_number] + e[mun_number,t]

        Estimated results:
                         |       Var     sd = sqrt(Var)
                ---------+-----------------------------
               consump~n |   4.963923       2.227986
                       e |   1.627386        1.27569
                       u |   1.923353        1.38685

        Test:   Var(u) = 0
                             chi2(1) =   226.29
                         Prob > chi2 =     0.0000
```

Before we resort to the Hausman test for the choice between random and fixed effects estimation, we perform tests for heteroskedasticity and autocorrelation, respectively through the commands xttest3 and xtserial. xttest3 implements a modified Wald test for group heteroskedasticity and we can see from Figure 5.8 that the null hypothesis of homoskedasticity is clearly rejected. xtserial implements an autocorrelation test discussed by Wooldridge (2001) for linear panel data models. Figure 5.8 shows that the null hypothesis of no autocorrelation in the residuals is also rejected. We adopt therefore a feasible GLS estimator developed by Baltagi and Wu (1999) and implemented through the Stata command xtregar.[32]

[32] In this apect, our procedure departs from Dalmas and Reynaud (2005) and Reynaud (2008), who perform the Hausman test after the BP-LM test without ttest for serial correlation, and is similar to the one used by Martins and Fortunato (2007).

Figure 5.8: Heteroskedasticity and autocorrelation tests

```
. quietly xtreg consumption mptotalz diftotalz fixedtotal income temp prec
seasonal_dwelling bathroom elder waterqual, fe
. xttest3

Modified Wald test for groupwise heteroskedasticity
in fixed effect regression model

H0: sigma(i)^2 = sigma^2 for all i

chi2 (267)  =   1.1e+31
Prob>chi2 =      0.0000


. xtserial consumption mptotalz diftotalz fixedtotal income temp prec seasonal_dwelling
bathroom elder waterqual

Wooldridge test for autocorrelation in panel data
H0: no first order autocorrelation
    F(  1,     197) =      7.603
           Prob > F =      0.0064
```

The Hausman test statistic for the comparison of the models with random and fixed effects has the value of 8.44, which corresponds to a p-value of 0.3921 in a $\chi^2(8)$. The test does not reject the null hypothesis of independence between the municipal effects and the exogenous regressors. Therefore, the GLS estimator is not only efficient but also consistent.

Figure 5.9 presents the estimation results. All coefficients have the expected signs and the great majority is significant at the 1% level. The value at the sample variable means for the price-elasticity of demand is -0.124, a relatively small value, but in line with the established result that water demand is price-inelastic. The estimated value is significantly lower than the value of -0.558 estimated by Martins and Fortunato (2007) for 5 Portuguese municipalities with monthly aggregate data[33] but is similar to the values estimated by Arbués-Gracia, Ortí and Martín (2008), Martínez-Espiñeira and Nauges (2004) and Martínez-Espiñeira (2002) respectively for Zaragoza, Seville and Galicia in Spain, Reynaud (2008) and Nauges and Reynaud (2001) for the southwest of France or

[33] Our own estimation with our data for the 5 municipallities used by Martins and Fortunato (2007) yielded a price-elasticity of -0.187, which reveals that this municipalities have an above average reaction to price changes, but most of the difference is probably explained simply by the fact that the data used by both studies has rather different characteristics. Dalhuisen et al. (2003) have shown that the frequency of the data can have a significantly impact on the estimated price-elasticity and that estimations from monthly data usually yield more elastic results than with annual data. The only comparable estimation performed on the INSAAR data for all Portuguese water utilities in 2002 was done by Martins and Fortunato (2004), but this work does not find a significant coefficient for the price variable.

Grafton and Ward (2007) for Sydney in the New South Wales region of Australia. All these regions have weather conditions similar to what can be found in Portugal. The income elasticity is 0.036, also a low value. Curiously, low values estimated for income elasticities are also not unheard of for regions at latitudes similar to Portugal and with close weather conditions as can be seen from Martínez-Espiñeira and Nauges (2004) for Spain, Nauges and Thomas (2000), Nauges and Reynaud (2001) and Garcia and Reynaud (2004) for France, Mylopoulos, Mentes and Theodossio (2004) for Greece, Nauges and Blundell (2002) for Cyprus, Yoo (2007) for South Korea, Barkatullah (1996) for Australia or Nieswiadomy and Molina (1991) for Texas, USA. The coefficients for the variables which together compose the usual "difference" variable in the Taylor-Nordin price specification, here decomposed into the block subsidy effect and the fixed charge, carry the expected negative signs but are not significantly different from zero. This may be a demonstration that consumers are not aware of the block subsidy effect or simply do not react to it for being small in comparison to their household income. The fact that $fixedtotal$ does not affect water demand is expected and supported by economic theory due to the fact that it is a fixed charge which does not vary with the amount of water consumed.

Figure 5.9: Estimation results

```
RE GLS regression with AR(1) disturbances       Number of obs      =       850
Group variable (i): mun_number                  Number of groups   =       267

R-sq:  within  = 0.0007                         Obs per group: min =         1
       between = 0.4181                                        avg =       3.2
       overall = 0.3360                                        max =         4

                                                Wald chi2(11)      =    192.44
corr(u_i, Xb)      = 0 (assumed)                Prob > chi2        =    0.0000

------------------- theta --------------------
  min      5%       median        95%      max
0.2532   0.3471     0.4618     0.4618   0.4618

------------------------------------------------------------------------------
 consumption |      Coef.   Std. Err.      z    P>|z|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
    mptotalz |  -1.514943   .4533426    -3.34   0.001    -2.403478   -.6264076
   diftotalz |  -.2115921   .1847499    -1.15   0.252    -.5736952     .150511
  fixedtotal |  -.0484121   .0682318    -0.71   0.478     -.182144    .0853197
      income |   .0769521   .0299292     2.57   0.010     .0182919    .1356124
        temp |   .2852466   .0831483     3.43   0.001     .1222789    .4482144
        prec |  -.0002155   .0001675    -1.29   0.198    -.0005438    .0001129
seasonal_d~g |  -3.989319   1.093954    -3.65   0.000    -6.133429   -1.845208
    bathroom |  -5.705003   2.127202    -2.68   0.007    -9.874242   -1.535765
       elder |   -8.28573   1.913328    -4.33   0.000    -12.03579   -4.535676
   waterqual |  -3.249893   1.568429    -2.07   0.038    -6.323957   -.1758281
       _cons |   7.260047   1.547328     4.69   0.000      4.22734    10.29275
-------------+----------------------------------------------------------------
      rho_ar |   .1783168   (estimated autocorrelation coefficient)
     sigma_u |  1.2073364
     sigma_e |  1.3339888
     rho_fov |  .45028633   (fraction of variance due to u_i)
------------------------------------------------------------------------------
```

The weather related variables have the expected signs, i.e., water demand increases with temperature and decreases with the amount of precipitation, although the coefficient for the latter is not significantly different from zero[34]. As expected, the % of seasonally inhabited dwellings has a significant negative effect on water consumption as does the % of houses without a bathtub or a shower. The negative coefficient for the % of people with 65 or more years of age confirms the previous findings. Finally the significant and negative coefficient for *waterqual* is a result which supports the view that consumers are aware of the tap water quality and do decrease their consumption when they consider it inadequate, perhaps turning to bottled water, private boreholes and wells or public fountains for their drinking and cooking water needs. This finding adds to the evidence brought up by Ford and Ziegler (1981), the only other study we are aware of that included delivered water quality as an explanatory factor for residential water demand.

Some authors like Foster and Beattie (1981) criticize the Taylor-Nordin price specification for assuming a fully informed consumer who is aware of the entire rate schedule and who responds to it accordingly. They argue that the consumer may only be aware of the total values of water expenditures and water consumption, supporting the use of an average price specification. Nieswiadomy and Molina (1991) apply the test procedure developed by Shin (1985) to test whether the consumer responds to the marginal or the average price (*aptotal*) of water. They consider the following "price perception variable", where k is the price perception parameter to be estimated:

$$P^* = mptotal \times \left(\frac{aptotal}{mptotal}\right)^k \tag{5.25}$$

A value of 0 for k would mean that consumers were responding to marginal price, rather than average price, while a value of 1 would have the opposite meaning. The adaptation of the test to our panel data framework proceeds as follows. The ratio $\frac{aptotal}{mptotal}$ (*perceived*) is included in a double-log functional form for water demand which is of subsequently

[34] Perhaps a different specification for the rainfall variable could be a better explanatory variable for residential water demand. For example, some authors like Olmstead et al. (2007) transform it into a measure of effective rainfall ans subtract it from potential evapotranspitation to get a variable representing the moisture requirement for lawns. Others like Schleich and Hillenbrand (2009) consider only the rainfall occured in the summer months. Hoffmann et al. (2006) choose to use the number of rainy days, instead of the actual amount of precipitation.

estimated (Z_{it} is the vector of the remaining exogenous regressors in logarithmic form and δ_3 the vector of their associated coefficients).

$$\ln consumption_{it} = \delta_1 + \delta_2 \ln mptotal_{it} + \delta_2 k \ln perceived_{it} + \delta_3 Z'_{it} + \alpha_i + \varepsilon_{it} \tag{5.26}$$

The error structure is similar to (5.21). k can be recovered after the estimation of (5.26) by dividing the coefficients associated with $\ln perceived$ and $\ln mptotal$. Because the endogeneity suspicions apply to the average price as well as the marginal price, we start by instrumenting it in the same fashion as we did with *mptotal* and *diftotal*.

$$aptotal_{it} = \psi_1 + \psi_2 fixedtotal_{it} + \psi_3 m3\_10_{it} + \psi_4 calc\_tariff_{it} + \alpha_i + \varepsilon_{it} \tag{5.27}$$

The estimation results from a random effects model for (5.27) are shown in Figure 5.10.

Figure 5.10: Random effects regression for *aptotal*

```
Random-effects GLS regression                   Number of obs      =       856
Group variable (i): mun_number                  Number of groups   =       268

R-sq:  within  = 0.5743                         Obs per group: min =         1
       between = 0.8227                                        avg =       3.2
       overall = 0.7979                                        max =         4

Random effects u_i ~ Gaussian                   Wald chi2(3)       =   2022.11
corr(u_i, X)       = 0 (assumed)                Prob > chi2        =    0.0000

------------------------------------------------------------------------------
     aptotal |      Coef.   Std. Err.      z    P>|z|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
  fixedtotal |   .1813971   .0053863    33.68   0.000     .1708401     .191954
       m3_10 |   .4828797   .0305547    15.80   0.000     .4229936    .5427658
 calc_tariff |   .0583706   .0162785     3.59   0.000     .0264653    .0902759
       _cons |   .1154036   .0187585     6.15   0.000     .0786376    .1521695
-------------+----------------------------------------------------------------
     sigma_u |  .12767887
     sigma_e |  .09362701
         rho |  .65030926   (fraction of variance due to u_i)
------------------------------------------------------------------------------
```

Figure 5.11 shows the low p-value for the Davidson and MacKinnon test of exogeneity indicates that the null hypothesis of exogeneity cannot be accepted with confidence, which supports the usual option on instrumenting the price variables in the presence of block tariffs[35].

[35] The Hausman test is not computable for this case.

Figure 5.11: Davidson and MacKinnon test of exogeneity for *aptotal*

```
. xtivreg consumption income temp seasonal_dwelling bathroom elder waterqual (aptotal =
fixedtotal m3_10 calc_tariff), fe

Fixed-effects (within) IV regression        Number of obs      =       850
Group variable: mun_number                  Number of groups   =       267

R-sq:  within  = 0.0026                     Obs per group: min =         1
       between = 0.0580                                    avg =       3.2
       overall = 0.0650                                    max =         4

                                            Wald chi2(5)       =  29141.60
corr(u_i, Xb)  = 0.1881                     Prob > chi2        =    0.0000

------------------------------------------------------------------------------
 consumption |      Coef.   Std. Err.      z    P>|z|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
     aptotal |  -.1085296   .4950299    -0.22   0.826     -1.07877    .8617112
      income |   .0233495   .0710764     0.33   0.743    -.1159577    .1626567
        temp |  -.0913173   .2123334    -0.43   0.667    -.5074831    .3248485
seasonal_d~g |  (dropped)
    bathroom |  (dropped)
       elder |  -2.640374   6.688423    -0.39   0.693    -15.74944    10.46869
   waterqual |  -.3808349   1.940894    -0.20   0.844    -4.184917    3.423247
       _cons |   9.441598   3.527226     2.68   0.007     2.528362    16.35483
-------------+----------------------------------------------------------------
     sigma_u |  2.0194139
     sigma_e |  1.2778256
         rho |  .71408243   (fraction of variance due to u_i)
------------------------------------------------------------------------------
F  test that all u_i=0:     F(266,578) =     4.26         Prob > F    = 0.0000
------------------------------------------------------------------------------
Instrumented:   aptotal
Instruments:    income temp seasonal_dwelling bathroom elder waterqual fixedtotal m3_10
calc_tariff

. dmexogxt

Davidson-MacKinnon test of exogeneity:  3.779982  F( 1,577)  P-value =  .0524
```

Figure 5.12 shows that the Anderson test rejects the null hypothesis of underidentification, thus supporting the relevance of the instruments chosen, while the Sargan test does not reject the null hypothesis of the instruments' validity. Separate difference-in-Sargan tests were performed on each instrument to check their individual validity as instruments for *aptotal*. None of the tests rejected the null.

Figure 5.12: Tests of instrument relevance and validity for *aptotal*

```
. xtivreg2 consumption income temp seasonal_dwelling bathroom elder waterqual (aptotal =
fixedtotal m3_10 calc_tariff), fe
Warning - singleton groups detected.  18 observation(s) not used.
Warning - collinearities detected
Vars dropped:  seasonal_dwelling bathroom

FIXED EFFECTS ESTIMATION
------------------------
Number of groups =       249                    Obs per group: min =         2
                                                               avg =       3.3
                                                               max =         4

IV (2SLS) estimation
--------------------

Estimates efficient for homoskedasticity only
Statistics consistent for homoskedasticity only

                                                      Number of obs =      832
                                                      F(  5,   578) =     0.10
                                                      Prob > F      =   0.9928
Total (centered) SS     =  946.2144463                Centered R2   =   0.0026
Total (uncentered) SS   =  946.2144463                Uncentered R2 =   0.0026
Residual SS             =  943.7805394                Root MSE      =    1.272

------------------------------------------------------------------------------
 consumption |      Coef.   Std. Err.      z    P>|z|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
     aptotal |  -.1085296   .4929026    -0.22   0.826    -1.074601    .8575417
      income |   .0233495    .070771     0.33   0.741    -.1153591     .162058
        temp |  -.0913173   .2114209    -0.43   0.666    -.5056946      .32306
       elder |  -2.640374    6.65968    -0.40   0.692    -15.69311    10.41236
   waterqual |  -.3808349   1.932553    -0.20   0.844    -4.168569    3.406899
------------------------------------------------------------------------------
Underidentification test (Anderson canon. corr. LM statistic):         332.424
                                                   Chi-sq(3) P-val =    0.0000
------------------------------------------------------------------------------
Weak identification test (Cragg-Donald Wald F statistic):              254.715
Stock-Yogo weak ID test critical values:  5% maximal IV relative bias    13.91
                                         10% maximal IV relative bias     9.08
                                         20% maximal IV relative bias     6.46
                                         30% maximal IV relative bias     5.39
                                         10% maximal IV size             22.30
                                         15% maximal IV size             12.83
                                         20% maximal IV size              9.54
                                         25% maximal IV size              7.80
Source: Stock-Yogo (2005).  Reproduced by permission.
------------------------------------------------------------------------------
Sargan statistic (overidentification test of all instruments):           1.623
                                                   Chi-sq(2) P-val =    0.4441
------------------------------------------------------------------------------
Instrumented:         aptotal
Included instruments: income temp elder waterqual
Excluded instruments: fixedtotal m3_10 calc_tariff
Dropped collinear:    seasonal_dwelling bathroom
------------------------------------------------------------------------------
```

After the model (5.26) was estimated (see results in Figure 5.13) the following nonlinear hypothesis were tested:

$$H_0 : \frac{\delta_2 k}{\delta_2} = 0 \tag{5.28}$$

$$H_0 : \frac{\delta_2 k}{\delta_2} = 1 \tag{5.29}$$

The test statistic for (5.28) is 0.23 which corresponds to a p-value of 0.6326 in a $\chi^2(1)$. The test statistic for (5.29) is 8.66 which corresponds to a p-value of 0.0033 in a $\chi^2(1)$. The result is therefore very clear. (5.28) is not rejected while (5.29) is, meaning that Portuguese consumers do respond to the marginal price and not to the average price of water.

Figure 5.13: Estimation result of the auxiliary model for the price perception test

```
RE GLS regression with AR(1) disturbances       Number of obs      =       807
Group variable (i): mun_number                  Number of groups   =       264

R-sq:  within  = 0.0027                         Obs per group: min =         1
       between = 0.5061                                        avg =       3.1
       overall = 0.4095                                        max =         4

                                                Wald chi2(9)       =    255.60
corr(u_i, Xb)      = 0 (assumed)                Prob > chi2        =    0.0000

------------------- theta --------------------
  min      5%       median        95%      max
0.2692   0.3527     0.4588     0.4588   0.4588

------------------------------------------------------------------------------
lnconsumpt~n |      Coef.   Std. Err.      z    P>|z|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
  lnmptotalz |  -.1084412   .0312263    -3.47   0.001    -.1696437   -.0472387
 lnperceived |   .0210365   .0409271     0.51   0.607     -.059179    .1012521
    lnincome |   .0886064   .0250027     3.54   0.000     .0396019    .1376108
      lntemp |   .6992438   .1396011     5.01   0.000     .4256307    .9728568
lnseasonal~g |   -.123602   .0300307    -4.12   0.000    -.1824611   -.0647429
  lnbathroom |  -.0442686   .0276573    -1.60   0.109    -.0984759    .0099388
     lnelder |  -.2146465   .0527708    -4.07   0.000    -.3180754   -.1112176
 lnwaterqual |  -.0087782   .0067355    -1.30   0.192    -.0219796    .0044231
       _cons |  -.7855641   .3730974    -2.11   0.035    -1.516822   -.0543067
-------------+----------------------------------------------------------------
      rho_ar |  .25861855   (estimated autocorrelation coefficient)
     sigma_u |  .15487805
     sigma_e |  .16016525
     rho_fov |  .48322229   (fraction of variance due to u_i)
------------------------------------------------------------------------------
```

5.7 Functional form specification tests

We now turn to the question of choice of functional form. Table 5.7 presents the estimation results for the functional forms considered in Tables 5.1 and 5.2. The nonsignificant variables from the Figure 5.9 were removed[36]. All coefficients retain the expected signs already seen in Figure 5.9. Only *bathroom* and *waterqual* have somewhat less significant coefficients in specific functional forms. All other coefficients are always significant at the 1% level.

Table 5.8 presents the calculations of the demand elasticities for the several functional forms considered.We can see that the results for the price-elasticities are generally robust to the choice of functional form, with only small variations between them.

To choose between the several functional forms presented in Table 5.7 we focus on three different methods:

- an encompassing approach (Mizon and Richard (1986));
- a comprehensive approach (the J test) (Davidson and MacKinnon (1981));
- the PE test (MacKinnon, White and Davidson (1983)).

The first two approaches will be used to compare nonnested models with the same dependent variable, while the PE test will be used to compare models where consumption is defined in natural logarithms with models where it is introduced without that transformation.

[36] Besides the usual advantages for efficiency of removing insignificant variable from an econometric model, the removal of *diftotal* has the additional advantage of enabling the estimation of the linlog and double-log models, because it has both negative, null and positive values.

Table 5.7: GLS regressions with AR(1) disturbances for several functional forms

Functional form	**Linear**	**Double-log**	**Log-lin**	**Lin-log**	**Stone-Geary**
Variable	Coef.	Coef.	Coef.	Coef.	Coef.
	(Std. Err.)	(Std. Err.)	(Std. Err.)	(Std. Err.)	(Std. Err.)
mptotalz	-1.236***	-0.111***	-0.154***	-0.910***	-
	(0.360)	(0.027)	(0.045)	(0.213)	-
income	0.079***	0.091***	0.010***	0.594***	-
	(0.030)	(0.025)	(0.004)	(0.193)	-
$(\text{income}*10^3)$/mptotalz	-	-	-	-	0.001***
	-	-	-	-	(0.000)
temp	0.342***	0.682***	0.049***	4.284***	0.330***
	(0.072)	(0.138)	(0.010)	(1.055)	(0.072)
seasonal_dwelling	-3.952***	-0.124***	-0.647***	-0.891***	-3.429***
	(1.087)	(0.030)	(0.140)	(0.226)	(1.055)
bathroom	-5.815***	-0.043†	-0.867***	-0.382*	-4.608**
	(2.120)	(0.027)	(0.273)	(0.209)	(2.056)
elder	-7.353***	-0.211***	-1.025***	-1.409***	-7.141***
	(1.840)	(0.052)	(0.235)	(0.394)	(1.844)
waterqual	-2.807*	-0.009	-0.374**	-0.065	-2.128
	(1.508)	(0.007)	(0.182)	(0.054)	(1.505)
intercept	5.864***	-0.734**	1.739***	-10.259***	4.841***
	(1.251)	(0.368)	(0.159)	(2.825)	(1.206)
N	873	830	873	830	873
Wald χ^2 (7)	188.82	259.42	246.29	211.40	184.07
Prob $>\chi^2$ (7)	0.000	0.000	0.000	0.000	0.000
Price-elasticity	-0.101	-0.111	-0.094	-0.122	-0.052
Income-elasticity	0.037	0.091	0.033	0.078	0.001

*** Significance at the 0.01 level
** Significance at the 0.05 level
* Significance at the 0.10 level
† Significance at the 0.15 level

Table 5.8: Summary of elasticity results for several functional forms

Functional form	**Linear**	**Double-log**	**Log-lin**	**Lin-log**	**Stone-Geary**
Variable	Elast.	Elast.	Elast.	Elast.	Elast.
mptotalz	-0.101	-0.111	-0.094	-0.122	-0.052
income	0.037	0.091	0.033	0.078	0.001
temp	0.700	0.682	0.748	0.574	0.675
seasonal_dwelling	-0.127	-0.124	-0.155	-0.119	-0.110
bathroom	-0.076	-0.043	-0.085	-0.051	-0.060
elder	-0.205	-0.211	-0.214	-0.189	-0.199
waterqual	-0.153	-0.009	-0.015	-0.009	-0.012

The encompassing approach starts by assuming one of the models being compared as the base model. Then it proceeds to create and estimate a model were the variables from the alternative model not included in the base model are added to it. The null hypothesis of the test is that the coefficients of these additional variables are all zero. A t-test or a Waldman F-test, depending on whether one or more additional regressors were added to the base model, is performed to test the null hypothesis and the validity of the base model. The role of each model can be reversed and the test performed again to the test the validity of the alternative model[37].

The comprehensive approach or J-test consists of adding to the base model the fitted values of the alternative model and testing whether or not they are significantly different from zero by means of a t-test[38]. The null hypothesis of a zero coefficient corresponds a valid base model.

Finally, the PE test for the validity of the model with the linear specification of the dependent variable (base model) involves adding to this base model the difference between the natural logarithm of the fitted values for the base model and the fitted values for the alternative model (the one with the dependent variable in logarithms). The null hypothesis that the coefficient of this additional regressor is zero, supports the linear model if it is not rejected and invalidates it against the alternative otherwise. To test the validity of the model with the dependent variable in logarithms we must add to the loglinear model the difference between fitted values of the linear model and the exponential function of the fitted values of the loglinear model. The null hypothesis for this second model states that the coefficient of this additional regressor is zero. If rejected it invalidates the loglinear model, but if not rejected, then it may be preferable. The PE test is an adaptation of the J-test for different dependent variables[39].

Table 5.9 shows the results of the relevant specification tests for comparing the different functional forms and the preferred one for each comparison. Summing up, we can see that the semilogarithmic functional form log-lin performs worst than any of the alternatives.

[37] See Greene (2003), p. 154, and Verbeek (2000), pp. 55-6, for further details.
[38] See Greene (2003), pp. 154-5, and Verbeek (2000), p. 56, for further details.
[39] See Greene (2003), pp. 178-80, and Verbeek (2000), p. 56-7, for further details.

The Stone-Geary form is also rejected when compared to the linear or to the lin-log semilogarithmic forms. The linear functional form is also not the preferred as it is discarded when compared to the lin-log alternative. The only alternative which is not rejected when compared with the lin-log is the double-log specification. The PE test rejects either form and none is preferred. The double-log specification is preferred to the semilogarithmic log-lin, but the tests fail to decide when it is compared to any of the other three alternatives. In the end we are left with an inconclusive choice between the semilogarithmic lin-log functional for and the double-log specification. This is unfortunate as we have seen that the former would justify IBT, while the latter would recommend an uniform volumetric rate (either of them coupled with a fixed charge, leading to a multi-part tariff for the former and a two-part tariff for the latter).

Table 5.9: Specification tests results and resulting preferred functional form

Funct. form	**Double-log**	**Log-lin**	**Lin-log**	**Stone-Geary**
Linear	undetermined	Linear	Lin-log	Linear
Encompassing	-	-	(H_0: linear; F-test: 0.070)	(H_0: linear; t-test: 0.365)
	-	-	(H_0: lin-log; F-test: 0.822)	(H_0: SG; F-test: 0.152)
Comprehensive	(H_0: linear; t-test: 0.016)	(H_0: linear; t-test: 0.537)	(H_0: linear; t-test: 0.002)	(H_0: linear; t-test: 0.365)
(J-test or PE-test)	(H_0: d-log; t-test: 0.003)	(H_0: log-lin; t-test: 0.000)	(H_0: lin-log; t-test: 0.558)	(H_0: SG; t-test: 0.065)
Double-log	-	Double-log	undetermined	undetermined
Encompassing		(H_0: d-log; F-test: 0.404)	-	-
		(H_0: log-lin; F-test: 0.025)	-	-
Comprehensive		(H_0: d-log; t-test: 0.227)	(H_0: d-log; t-test: 0.000)	(H_0: log-lin; t-test: 0.020)
(J-test or PE-test)		(H_0: log-lin; t-test: 0.001)	(H_0: lin-log; t-test: 0.002)	(H_0: SG; t-test: 0.001)
Log-lin	-	-	Lin-log	Stone-Geary
Comprehensive			(H_0: log-lin; t-test: 0.000)	(H_0: log-lin; t-test: 0.535)
(J-test or PE-test)			(H_0: lin-log; t-test: 0.472)	(H_0: SG; t-test: 0.002)
Lin-log	-	-	-	Lin-log
Encompassing				(H_0: lin-log; F-test: 0.783)
				(H_0: SG; F-test: 0.031)
Comprehensive				(H_0: lin-log; t-test: 0.639)
(J-test or PE-test)				(H_0: SG; t-test: 0.000)

Our analysis of the Portuguese residential water demand does not enable us to conclude if the IBT universally applied by the Portuguese water utilities for residential water supply and to a much lesser extent to the wastewater component of the water bill can be grounded on efficiency reasons, besides the usual justifications for its implementation based on equity or water conservation concerns. We were, nevertheless, unable to dismiss this possibility when the conditions described by Roseta-Palma and Monteiro (2008) apply.

5.8 Conclusion

We tested the conditions derived by Roseta-Palma and Monteiro (2008) for IBT to be a second-best pricing practice under water scarcity and budget balancing constraints, when consumers are heterogeneous and the fixed charge is only allowed to cover fixed costs and not to act as a lump sum charge in order to guarantee cost recovery by the water utility. The choice of functional form, which is most usually based on convenience for the practical research objective at hand, is shown to be essential in determining the outcome of such a test. While a linear or semilogarithmic specifications would lead us to conclude that IBT are justified, a double-log functional form would recommend a uniform volumetric rate and a Stone-Geary specification would make the choice of tariff schedule design dependent on the estimated values of the coefficients associated with each regressor.

We estimate residential water demand for Portugal for a panel of annual data at the municipal level for four different years through a random effects GLS estimator with AR(1) disturbances and make the choice of functional form dependent on the appropriate statistical specification tests for comparing each pair of alternative hypothesis (like the J-test or the PE-test). We are left with an inconclusive choice between a semilogarithmic lin-log functional form and a double-log specification. Therefore it has not been proved that the use of IBT can have efficiency justifications, besides the usual equity and water conservation concerns, but such possibility could not be dismissed.

The results for the water demand determinants confirm that residential water demand does respond to the marginal and not to the average price, although it is inelastic. Besides the usual positive impact of income, temperature and water using appliances and the negative impact of the proportion of elderly people, we show that the proportion of seasonally inhabited dwellings and a reduced water quality on delivery can have a significant negative influence on the amount of water households consume.

Future research on the Portuguese water demand could try to improve the data available, gathering household level information to explicitly model the choice of consumption block and include more specific household characteristics, like gardens and pools. Intra-annual data would also be valuable in the identification of seasonal consumption patterns or in the separation of indoor and outdoor water demand, enabling further research on whether seasonally differentiated tariffs are called for. Furthermore, if the frequency of observations was similar to the billing frequency, lagged price specifications coud be tested and the speed of adoption of water saving measures in response to higher prices could also be investigated. Finally, the combination of water demand estimations with research on the costs of water supply and sewerage would be valuable to better assess the potential of the tariff schedules to contribute to the objectives set out by the Water Framework Directive for 2010 regarding the establishment of efficient water prices and adequate cost recovery levels. Furthermore, if cost savings could be made, by the water utilities by seizing economies of scale for example, adequate cost recovery levels might be achieved with a lesser impact on tariffs and consumers.

Chapter 6

Estimation of Cost Functions for the Portuguese Water and Wastewater Industry

6.1 Introduction

Water policy in Portugal, as in many other countries, is currently focused on two main issues: demand management and water supply. On the demand side, the focus has been on the implementation of the management policies advocated by the European Water Framework Directive in 2000 (EU (2000)) and transcribed in the new Portuguese Water Law in 2005 (AR (2005)) and the new Economic and Financial Regime for Water Resources in 2008 (MAOTDR (2008*a*)). The principle of adequate cost recovery (including scarcity and environmental costs) has led to the creation of a water resources charge, which will put a price on the water resources abstracted from the environment and help finance the newly created River Basin Authorities. The new tariff regulation, prepared by the Regulating Authority on Water and Waste Services (ERSAR, ex-IRAR) will help to bring some harmonization and to introduce increased concerns with water use efficiency and cost recovery into the design of water tariffs for final users. There is also an explicit concern with the promotion of water use efficiency (LNEC-ISA (2001)).

The supply side is mainly guided by the Second National Strategic Plan for Water Supply, Sewerage and Waste Water - PEAASAR II 2007-2013 (MAOTDR (2007*a*)), which states the amounts of public European and national governmental funding which will be allocated to the required investments in the industry, namely to improve the levels of population covered by adequate water supply and wastewater drainage and treatment services. A plan to build ten large water dams was recently approved, but these are mainly focused on the generation of electricity from hydropower, although they will also add to the national strategic water reserves for water supply and a few of them could also benefit irrigation farming (COBA-PROCESL (2007)). Thus, we can say that a combination of water demand management policies is being coupled with water supply enhancing investments. This paper focus on the supply side.

Two of the structural problems identified by PEAASAR II in the Portuguese water industry are (MAOTDR (2007*a*), p.33):

- "The existence of a significative number of small systems, unable to seize economies of scale";

- "The separate management of water supply and wastewater sewerage, lacking integration from the perspective of the urban water cycle, ruling out a correct articulation between abstractions and rejections".

In response to the identified problems the plan seeks to promote economies of scale and scope in the industry, mainly at the bulk water level where the fusions of different multimunicipal systems are explicitly called for where these types of economies could be seized, but also at the retail level. Economies of scale exist when an increase in output is associated with a less than proportional increase in costs, which implies a decreasing average cost. Diseconomies of scale exist if there is a more then proportional increase in costs associated to an increase in output[1]. Scope economies exist when the cost of jointly producing a set of outputs is less than the sum of the costs of their separate production by specialized firms (Cabral (2000), pp. 23-4). Economies of scope can be positive, null or negative[2].

[1] The concept of economies of scale can be associated with but is not the same as returns to scale. The latter is a measure of how output varies relative to proportional increases in all inputs. Returns to scale are said to be increasing, decreasing or constant if the output increases proportionally more, less or the same, respectively, relative to the input increase in scale.

[2] In our case, a situation of positive scope economies would mean that the costs for a single utility of providing both water supply and sewerage would be less than the sum of the costs of two utilities providing the two services separately.

The formulated strategy for the territorial organization of the retail part of the business is said to be based on the following principle (among others): "territorial integration of the solutions in a plurimunicipal logic, similar to what already happens in the "bulk" part, and involving the water supply and wastewater sewerage components, enabling the generation of economies of scale and scope and the solidary and articulated solution of the coverage problem in the area of intervention of each system" (MAOTDR (2007*a*), p.57). The public holding company for the industry has already been playing a significant role in promoting this solution to the municipalities responsible for the retail systems. Solving supply problems at the retail level is the main challenge for the period 2007-2013, after the previous plan had a greater impact at the bulk level, during the period 2000-2006. The choice of the best management model (regarding size and system connections in addittion to ownership), together with the investment in infrastructure to improve coverage levels, as well as the adoption of tariffs that promote water use efficiency and the financial sustainability of water utilities (matching cost recovery concerns with the population's economic means) make up the set of the three main problems to be addressed.

For all these reasons, this is the right time to be thinking about whether the Portuguese water industry is seizing the opportunities to grab hold of the possible scale and scope economies revealed by its cost structure. Our paper seeks to contribute to this discussion through the estimation of the cost function for water supply and wastewater drainage and treatment in the Portuguese industry. We review the literature on the econometric estimation of the water cost function in section 6.2. Section 6.3 presents the models and the methodology used, while section 6.4 present the database. The estimation results and the findings regarding economies of scale and scope are described in sections 6.5, 6.6 and 6.7. Section 6.8 concludes.

6.2 Literature review

The literature concerning the econometric estimations for the water supply cost function started in the end of the 1960's with the works of Ford and Warford (1969) for a cross section of 162 water utilities in England and Wales and Hines (1969) for a thirteen-year panel of 52 water utilities in Wisconsin, USA. The number of published studies has grown since, with cross-sectional databases dominating until the turn of the century and panel databases assuming a more prominent role since. Studies based on single-utility time-series data are scarcer[3].

Several econometric estimation techniques have been applied in the field. The initial use of ordinary least squares has by now virtually subsided and other methods have taken its place like seemingly unrelated regressions (SUR), maximum likelihood estimation and panel data techniques like random effects estimators or GMM. The most common method is SUR, developed by Zellner (1962) and applied to the estimation of the water cost function in combination with the inputs' cost shares, through the use of Shephard's lemma, as we shall see below.

The initial studies published used mostly data from the USA. The first publication, to our best knowledge, to use data from other than North America (USA and Canada) or the UK was Kim and Lee (1998) which used a panel of 42 utilities from South Korea, more than thirty years after the seminal works. The last decade has seen some more research in other European countries like Italy (Fabbri and Fraquelli (2000)), France (Garcia and Thomas (2001)), Germany (Sauer (2005)), Spain (García-Valiñas (2005*a*)) and Slovenia (Filippini, Hrovatin and Zoric (2008)). A number of works have also been undertaken in Japan (Mizutani and Urakami (2001)) and in developing countries. The latter consisted not only of studies for specific countries like Corton (2003) and Lin (2005), but also of international databases like the IBNET[4] to pool utilities from Eastern Europe, Latin America, Africa and Asia (Nauges and Berg (2008*b*) and Nauges and Berg (2008*a*)) or the Water Utilities Data Books provided by the Asian Development Bank to pool utilities from Asian and Pacific countries (Estache and Rossi (2002)). For Portugal, three studies can be found in unpublished working papers (Martins, Fortunato and Coelho (2006), Martins et al. (2008) and Sampaio (2008)).

The dependent variable for these studies is usually either the total or the variable/operating

[3]The works of Renzetti (1992) for Vancouver, Canada, and García-Valiñas (2005*a*) for Seville, Spain, are exceptional cases using time-series data for a single utility.

[4]IBNET - The International Benchmarking Network for Water and Sanitation Utilities, http://www.ib-net.org/.

cost of the water utility (a few early studies used unit costs instead of total values for the utility). Essential to the definition of the cost function are the outputs produced. The volume of water delivered is naturally the obvious first regressor to include. When data on the amount of water delivered is not available, is usually replaced by water produced, which is the sum of the surface water diversions, groundwater pumping and bulk water acquisitions. When, on the contrary, the available data was more detailed, some authors were able to use multi-output specifications and separate residential from other nonresidential water uses (Renzetti (1992), Kim (1995) and Renzetti (1999)), bulk water supply to other utilities from retail water supply to final customers (Torres and Paul (2006) and Garcia, Moreaux and Reynaud (2007)) or to consider water delivered and water losses as two outputs (one desired, the other not) (Garcia and Thomas (2001) and Martins et al. (2008)). The multi-ouput framework has also been used by several authors to estimate cost functions considering both the water supply and the wastewater collected (Lynk (1993) and Martins, Fortunato and Coelho (2006) are respectively an early and a recent example). Feigenbaum and Teeples (1983), Lynk (1993) and Hunt and Lynk (1995) additionally consider the environmental service provided by the water industry. Feigenbaum and Teeples (1983) includes it in the list of regressors for an index of output (the output hedonic function estimates are included in a second step in the cost function), while the other two studies consider it directly in the cost function as an equally standing output like water supply and wastewater collected. Finally, Fraquelli, Piacenza and Vannoni (2004) considers a multi-output framework combining water, gas and electricity supply, but this approach is not relevant for Portugal, at least at the retail level that our study considers[5].

The other usual regressors are the input prices, namely for labour[6], capital, energy, consumables/chemicals and contracted out services. No matter how much disaggregation has been applied by the researcher, a category for some miscellaneous inputs is tipically added, not only because of the natural heterogeneity in this residual category of inputs, but

[5] At the bulk water level it might be more relevant due to recents trends related to the operation of small hydropower facilities, biogas from controlled waste landfills and electricity generation from urban and industrial solid waste burning.

[6] Teeples and Glyer (1987*b*) and Renzetti (1992) have further subdivided labour inputs into two or more different categories.

also because one or more of the aforementioned inputs often can't be measured separately.

The number of customers and the length of the water distribution/wastewater collection network are also common among the chosen regressors, in order to disaggregate the estimated value for the scale economies into returns for output, customer density, or even spatial density. Other possible explaining factors are: area served; pumping and storage capacity; % of water delivered to nonresidential customers; % of metered connections; % of raw water undergoing a given level of treatment[7]; types of water sources; drinking water quality measures; % of water losses[8]; service interruptions.

An additional factor deserves special attention. The type of ownership, public or private, is also often included as an explaining factor. Moreover, testing the hypothesis that these two types of ownership are associated with different efficiency levels has been the drive of much of the research in this literature, the estimation of the cost function being an obvious tool for that goal[9]. Because efficiency is the main concern and the hypothesis is that not all water utilities operate at the minimum possible cost, many studies estimate stochastic cost frontiers rather than cost functions for the average utility in the sample[10]. The ownership effects are, according to Martins et al. (2008), only one of the three main motivations for the estimation of the water cost function. The other two are the design of optimal price schemes and the test of the existence of economies of scale and scope. While this paper will focus on the latter issue, the estimation of the cost function for the water industry is also an important step for the future assessment of the characteristics of the Portuguese tariff schedules regarding efficiency and cost recovery[11].

The most widely used functional form is the transcendental logarithmic, introduced by Christensen, Jorgenson and Lau (1971) and first used to estimate a water cost function by Feigenbaum and Teeples (1983). It may be interpreted as a second-order Taylor-series

[7] Which is used in alternative to the raw water quality.

[8] Or alternatively, the ratio of water delivered to the water produced.

[9] An alternative literature exists on the measurement of water utilities' eficiency based on data envelopment analysis, but it falls outside the scope of our study. See Renzetti and Dupont (2008) for a recent example.

[10] See Renzetti and Dupont (2004) for an overview of the literature focused on the question of ownership and with a concern for the separation of cost functions and cost frontiers.

[11] Renzetti (1992), Kim (1995), Garcia and Reynaud (2004) and García-Valiñas (2005*a*) are examples of studies combining the analysis of water demand and supply to assess the porperties of water tariff schedules.

approximation to the true cost function rather that the function itself. It is considered a flexible functional form enabling elasticities of substitution and economies of scale to differ for different output and cost levels. The loglinear form derived from the Cobb-Douglas functional form for costs also enjoys some popularity, thanks to its ease of estimation and the interpretation of coefficients as elasticities. The use of other specifications is rarer.

6.3 Models and methodology

We estimate three total cost function models, one for the water supply industry, another for the wastewater drainage and treatment activity and a third combining both activities. We choose the transcendental logarithmic (translog) functional form for its flexibility in approximating the true total cost function. This functional form is the most widely used specification in water cost function estimation studies. The model for water supply is:

$$\begin{aligned}\ln\left(TC_{it}^{WS}\right) = {} & \alpha_0 + \sum_q \alpha_{Yq} \ln\left(Y_{qit}^{WS}\right) + \alpha_C \ln\left(C_{it}^{WS}\right) + \sum_j \alpha_j \ln\left(P_{jit}^{WS}\right) + \\ & + \frac{1}{2}\sum_q \sum_r \alpha_{Yqr} \left(\ln\left(Y_{qit}^{WS}\right) \ln\left(Y_{rit}^{WS}\right)\right) + \frac{1}{2}\alpha_{CC}\left(\ln\left(C_{it}^{WS}\right)\right)^2 + \\ & + \frac{1}{2}\sum_j \sum_k \alpha_{jk} \left(\ln\left({P^{WS}}_{jit}\right) \ln\left(P_{kit}^{WS}\right)\right) + \sum_q \alpha_{YqC} \ln\left(Y_{qit}^{WS}\right) \ln\left(C_{it}^{WS}\right) + \\ & + \sum_q \sum_j \alpha_{Yqj} \ln\left(Y_{qit}^{WS}\right) \ln\left(P_{jit}^{WS}\right) + \sum_j \alpha_{Cj} \ln\left(C_{it}^{WS}\right) \ln\left(P_{jit}^{WS}\right) + \\ & + \sum_m \alpha_{Zm} \ln\left(Z_{mit}^{WS}\right) + \sum_n \alpha_{Dn} D_{it}\end{aligned} \tag{6.1}$$

where TC stands for total costs and Y, C and P represents outputs, number of customers and inputs, respectively. $j, k \in \left\{L^{WS}, B^{WS}, OT^{WS}\right\}$ are indexes for the three different inputs considered, labour, bulk water and all others (except capital, but including energy) and $q, r \in \{delivered, losses\}$ are indexes for the two types of outputs considered, delivered water and water losses. Z_m^{WS} stands for the M additional relevant technical variables included in the regression in logarithms separately, while D are additional dummy variables. The same translog specification is used for the estimation of the wastewater drainage and treatment cost functions, except that the number of outputs is reduced to one, the amount of wastewater collected, besides the obvious necessary adaptations in interpretation of the remaining explanatory variables. The equation for the wastewater drainage and treatment costs reads:

$$\begin{aligned}\ln\left(TC_{it}^{WW}\right) = {} & \beta_0+\beta_Y\ln\left(Y_{it}^{WW}\right)+\beta_C\ln\left(C_{it}^{WW}\right)+\sum_j\beta_j\ln\left(P_{jit}^{WW}\right)+ \\ & +\frac{1}{2}\beta_{YY}\left(\ln\left(Y_{it}^{WW}\right)\right)^2+\frac{1}{2}\beta_{CC}\left(\ln\left(C_{it}^{WW}\right)\right)^2+ \\ & +\frac{1}{2}\sum_j\sum_k\beta_{jk}\left(\ln\left({P^{WW}}_{jit}\right)\ln\left(P_{kit}^{WW}\right)\right)+\beta_{YC}\ln\left(Y_{it}^{WW}\right)\ln\left(C_{it}^{WW}\right)+ \\ & +\sum_j\beta_{Yj}\ln\left(Y_{it}^{WW}\right)\ln\left(P_{jit}^{WW}\right)+\sum_j\beta_{Cj}\ln\left(C_{it}^{WW}\right)\ln\left(P_{jit}^{WW}\right)+ \\ & +\sum_f\beta_{Zf}\ln\left(Z_{fit}^{WW}\right)+\sum_g\alpha_{Dg}D_{it}\end{aligned} \tag{6.2}$$

where $j,k\in\left\{L^{WW},B^{WW},OT^{WW}\right\}$ is an index for the three different inputs considered, labour, bulk wastewater collection and all others (except capital, but including energy). Z_f^{WW} stands for the F additional relevant technical variables included in the regression separately, while D are additional dummy variables.

The specification for the multi-output cost function differs in that it considers two outputs, the amount of water supplied and the volume of wastewater collected. Moreover, the length of the distribution network has to be discarded for the model to be estimated due to the amount of missing data it contains. The adapted model is then:

$$\begin{aligned}\ln\left(TC_{it}\right) = {} & \gamma_0+\sum_q\gamma_{Yq}\ln\left(Y_{qit}\right)+\sum_q\gamma_{Cq}\ln\left(C_{qit}\right)+\sum_j\gamma_j\ln\left(P_{jit}\right)+ \\ & +\frac{1}{2}\sum_q\sum_r\gamma_{Yqr}\left(\ln\left(Y_{qit}\right)\ln\left(Y_{rit}\right)\right)+\frac{1}{2}\sum_q\sum_r\gamma_{Cqr}\left(\ln\left(C_{qit}\right)\ln\left(C_{rit}\right)\right)+ \\ & +\frac{1}{2}\sum_j\sum_k\gamma_{jk}\left(\ln\left(P_{jit}\right)\ln\left(P_{kit}\right)\right)+\sum_q\sum_r\gamma_{YCqr}\ln\left(Y_{qit}\right)\ln\left(C_{rit}\right)+ \\ & +\sum_q\sum_j\gamma_{Yqj}\ln\left(Y_{qit}\right)\ln\left(P_{jit}\right)+\sum_q\sum_j\gamma_{Cqj}\ln\left(C_{qit}\right)\ln\left(p_{jit}\right)+ \\ & +\sum_h\gamma_Z\ln\left(Z_{hit}\right)+\sum_l\alpha_{Dl}D_{it}\end{aligned} \tag{6.3}$$

where $j,k\in\{L,B,OT\}$ is an index for the three different inputs considered, labour, bulk water/wastewater and all others (except capital, but including energy) and $q,r\in\{delivered, collected\}$ are indexes for the two types of outputs considered water supply and wastewater collection[12]. Z_h stands for the H additional relevant technical variables included in the regression separately, while D are additional dummy variables..

[12]Water losses could not be considered because the number of parameters to be estimated would be greater than the available observations.

In the previous equations (6.1), (6.2) and (6.3), i is a water utility index, t is a time index. The α's, β's and γ's are the parameters to be estimated. The estimated equation assumes the usual symmetry conditions on the Hessian matrix: $\alpha_{jk} = \alpha_{kj}$, $\alpha_{Yqr} = \alpha_{Yrq}$ (model (6.1)), $\beta_{jk} = \beta_{kj}$ (model (6.2)), $\gamma_{jk} = \gamma_{kj}$, $\gamma_{Yqr} = \gamma_{Yrq}$ and $\gamma_{Cqr} = \gamma_{Crq}$ (model (6.3)). Homogeneity of degree one in inputs is imposed by dividing the costs and the input prices of labour, bulk water/wastewater and others by the price of capital[13].

We assume the utilities operate at their cost minimizing optimum and apply Shephard's lemma[14] to obtain the following equations for the inputs' cost-shares associated with models (6.1), (6.2) and (6.3), respectively[15]:

$$S_{jit}^{WS} = \frac{P_{jit}^{WS} x_{jit}^{WS}}{TC_{it}^{WS}} = \frac{\partial \ln TC^{WS}}{\partial \ln p_j^{WS}} = \alpha_j + \sum_k \alpha_{jk} \ln \left({P^{WS}}_{kit} \right) + \quad (6.4)$$
$$+ \sum_q \alpha_{Yqj} \ln \left(Y_{qit}^{WS} \right) + \alpha_{Cj} \ln \left(C_{it}^{WS} \right)$$

$$S_{jit}^{WW} = \frac{P_{jit}^{WW} x_{jit}^{WW}}{TC_{it}^{WW}} = \frac{\partial \ln TC^{WW}}{\partial \ln p_j^{WW}} = \beta_j + \sum_k \beta_{jk} \ln \left({P^{WW}}_{kit} \right) + \quad (6.5)$$
$$+ \beta_{Yj} \ln \left(Y_{it}^{WW} \right) + \beta_{Cj} \ln \left(C_{it}^{WW} \right)$$

$$S_{jit} = \frac{P_{jit} x_{jit}}{TC_{it}} = \frac{\partial \ln TC}{\partial \ln p_j} = \gamma_j + \sum_k \gamma_{jk} \ln \left(P_{kit} \right) + \quad (6.6)$$
$$+ \sum_q \gamma_{Yqj} \ln \left(Y_{qit} \right) + \sum_q \gamma_{Cqj} \ln \left(C_{qit} \right)$$

We use the method of estimation developed by Zellner (1962) for the estimation of seemingly unrelated regression equations to jointly estimate the following system composed by the translog equation and by the cost shares. We do not consider the capital cost share in the following simultaneous equations estimation procedures to avoid the singularity of the variance-covariance matrix of errors[16]. We assume no specific effects exist and that

[13] This is equivalent to the imposition of the following restrictions: $\sum_j \alpha_j = 1$, $\sum_j \alpha_{jk} = 0$, $\sum_j \alpha_{Yj} = \sum_j \alpha_{Cj} = 0$ (model (6.1)); $\sum_j \beta_j = 1$, $\sum_j \beta_{jk} = 0$, $\sum_j \beta_{Yj} = \sum_j \beta_{Cj} = 0$ (model (6.2)); $\sum_j \gamma_j = 1$, $\sum_j \gamma_{jk} = 0$, $\sum_j \gamma_{Yqj} = \sum_j \gamma_{Cqj} = 0$ (model (6.3)); where $j, k \in \{L, B, K, OT\}$ is an index for the four different inputs considered, labour, bulkwater/wastewater, capital and all others (including energy). This is the reason why capital is not considered in equations (6.1), (6.2) and (6.3).

[14] See Varian (1992), p. 74 or Mas-Collel, Winston and Green (1995), p. 141.

[15] x_{jit} is the derived demand of input j by utility i in year t.

[16] We used the SUREG procedure from STATA 9.2 software.

the error component is white noise. The common procedure of mean-scaling all variables (except dummies) as been applied, i.e., they were divided by their respective sample mean before the logarithmic transformation. In this way, the estimated first-order coefficients are all interpretable as cost elasticities evaluated at the sample mean.[17]

6.4 The data

Our research in this paper focuses on the utilities operating at the retail level, i.e., providing water services to households and other nonresidential customers and not on the wholesale operators whose main activity is to provide bulk water to other utilities or to collect and treat wastewater from them. Data on 289 water and wastewater utilities' costs, number of customers, volumes supplied/collected and the length of the water/wastewater distribution/collection networks was provided by the Portuguese National Water Institute (INAG) from the National Inventory of Water Supply and Wastewater Systems (INSAAR) for the years 2002 and 2005[18], covering all municipalities of mainland Portugal[19]. In 260 municipalities, the utilities provide both water supply and sewerage services, but in the remaining cases there are different utilities for each service (usually, the municipality concedes the water supply operation and continues to operate the sewerage network). We found one case where the retail water supply operation covering five municipalities was provided by a single utility, but each municipality managed their own separate sewerage service. This results in having 271 utilities providing water supply, 275 draining and treating wastewater and a combined set of 289 utilities to consider in a multiproduct framework. The available database is an unbalanced panel for the study period. Direct collection of additional information on volumes supplied/collected and the number of customers from the water and wastewater utilities of each municipality improved the data for those categories, but significant missing data remains, specially regarding the price of

[17] At the sample mean, the mean scaled variables will have the value of one, rendering their logarithmic transformation null. The extra terms in the cost elasticities formulas resulting from the second-order terms in the translog equation disappear at the sample mean, leaving the straightforward result: $\frac{\partial \ln(TC_{it})}{\partial(\ln(X_{it}))} = \beta_X$

[18] The database also included the years 1998 and 2000, but for those years there was a large enough amount of missing data to prevent its use.

[19] We only consider the retail service providers, although the database did include information on bulk water and wastewater operators.

labour[20].

Tables 6.1 and 6.2 show the definition of the main variables used in the water supply cost function model[21] and some summary statistics[22].

Table 6.1: Definition of the variables used in the water supply cost function

Variable	**Definition**
TC^{WS}	Total cost of water supply (€/year)
$Y^{WS}_{delivered}$	Volume of water delivered (m^3/year)
Y^{WS}_{losses}	Estimated volume of water losses (m^3/year)
C^{WS}	Number of water supply customers
P^{WS}_{L}	Labour price index in water supply (€/m^3 of water delivered)
P^{WS}_{B}	Bulk water price (€/m^3)
P_K	Price of capital (harmonized long-term interest rates for convergence assessment purposes) (%)
P^{WS}_{OT}	Price index for other miscellaneous inputs in water supply, including energy (€/m^3)
multimunicipalWS	Existence of a multimunicipal bulk water provider for the municipality
customerdensityWS	C^{WS}/area of the municipalities served (customers/km^2)
S^{WS}_{L}	Share of labour costs in total costs of water supply
S^{WS}_{B}	Share of bulk water acquisition costs in total costs of water supply
S_K	Share of capital costs in total costs of water supply
S^{WS}_{OT}	Share of costs with other miscellaneous inputs, including energy, in water supply

The total cost of water supply is calculated as the sum of the following categories of costs: labour costs, bulk water purchases, capital costs and other operational costs (including energy). The lack of disaggregation of the operating costs by the utilities is responsible for a significant amount of missing data regarding labour costs. We must also mention that not all water utilities purchase bulk water. Multimunicipal bulk water systems are still being expanded in Portugal and they do not cover the entire country[23]. Our choice to consider the bulk water costs as a separate category prevents us from using observations

[20] Missing data was the reason why the length of the water distribution/wastewater collection network was not considered.

[21] Other variables were considered in preliminary analysis, but they were dropped for not being significant or simply because the number of available observations in the panel limited the number of regressors which could be considered Examples of such variables were precipitation, % of missing mandatory water quality analysis, altitude difference between the highest and the lowest point in the municipality, % of water produced from bulkwater acquisitions, volume of water losses, % of population served by water supply systems, % of detached houses (proxy for meter reading costs), frequency of billing and type of utility dummy variables.

[22] The estimation considered regional dummies at the NUTS II level, which are not included in the tables.

[23] The data considers the cases of bulk water purchases from neighbouring municipal operators, but they are a fraction of the bulk water transactions.

Table 6.2: Summary statistics of the variables used in the water supply cost function - all water utilities

Variable	N	Mean	Std. Dev.	Min.	Max.
TC^{WS}	526	2,471,713	5,856,423	1,915	5.39×10^7
$Y^{WS}_{delivered}$	542	2,078,061	4,767,810	104,514	6.56×10^7
Y^{WS}_{losses}	542	1,109,162	3,056,561	0	4.67×10^7
C^{WS}	532	16,812	32,028	1,261	341,799
P^{WS}_{L}	170	0.261	0.201	0.006	1.122
P^{WS}_{B}	379	0.403	0.148	0	1.57
P_K	542	3.955	0.496	3.46	4.45
P^{WS}_{OT}	483	0.366	0.449	0.001	3.947
multimunicipalWS	542	0.614	0.487	0	1
area	542	328.2	287.8	7.9	1,720.6
customerdensityWS	532	132.2	413.7	2.2	4,035.4
S^{WS}_{L}	186	0.206	0.138	0.006	0.640
S^{WS}_{B}	526	0.103	0.185	0.000	0.849
S_K	526	0.337	0.196	0.002	0.942
S^{WS}_{OT}	481	0.238	0.189	0.000	0.904

from the utilities that do not buy bulk water[24]. Nevertheless, the impact is marginal, given that usually the utilities located outside the scope of the multimunicipal bulk water systems are usually from in less populated rural areas and tend not to disaggregate operation costs entirely, meaning they tend to be discarded due to missing data anyway[25]. The capital costs considered result from the calculation of equivalent annuities for a 30-year term of maturity of a deflated[26] series of investments for the period 1987-2005, to which we add financial outlays.

The volume of water losses is calculated from the difference between the amount of water produced from all sources (including bulk water purchases) and the volume of water delivered. This data is available in the Regional Statistics published by the National Statistics Institute (INE).

[24] We do not transform null observations on variables. Where they appear, the utility is discarded in the same fashion as the missing data cases.

[25] We do realize however, that our estimation results may represent only the cases where a bulk water provider exists and may lack the ability to be generalized for the remaining retail operators.

[26] We used the deflator for Portuguese GDP at market prices, unit Euro/ECU, supplied by AMECO – Annual Macroeconomic Database of Directorate General for Economic and Financial Affairs (DG ECFIN) of the European Commission) and considered constant 2005 prices.

The price of labour (P_L^{WS}) is calculated as an index based on the ratio of labour costs per m^3 of water delivered, due to lack of data on the number of employees, adapting an approach used commonly for the residual cost category[27] (the same procedure is in fact used for the residual cost category in our study). Energy expenditures have not been considered separately in equation (6.1) due to the lack of variation in the corresponding price.[28]

The set of Z_m^{WS} variables included in equation (6.1) will only include a measure of the density of customers served ($customerdensityWS$)[29]. Dummy variables were created to capture regional differences in the conditions of operation. We also consider a dummy variable with a value of one if there is a multimunicipal bulk water provider for the municipality[30]. Finally, the cost shares are calculated from the INSAAR data.

Tables 6.3 and 6.4 show the definition of the main variables used in the wastewater drainage and treatment cost function model and some summary statistics. The aforementioned considerations apply. The separation of costs between the water supply and sewerage activity was done by the utilities at the time of the data collection by the National Water Institute.

[27] See for example Garcia and Thomas (2001). An alternative is the division by the amount of capital assets or a proxy like the network length (Bottasso and Conti (2009) and Filippini et al. (2008)). The alternative would not be a good choice in our case due to the missing data regarding network length.

[28] All the utilities face the same regulated price schedules, as long as they choose the same power load capacity. Variation in the price of energy would only came from the temporal dimension of the panel which is only two years.

[29] Other variables were considered in preliminary analysis, but they were dropped for not being significant. Examples of such variables were the % of water produced from different sources (groundwater, surface, bulkwater purchases), measures of water quality, billing frequency, temperature and precipitation, altitude difference between the highest and the lowest point in the municipality, % of population served by water supply or by wastewater collection systems and treatment plants or the % of output to nonresidential customers. Some of these variables showed relevance in preliminary tests without the mean-scaling transformation, but not in the models where it was applied.

[30] The value of zero stands for the cases where bulk water is purchased from neighbouring municipalities, given that the cases which do not buy bulk water and are not covered by a multimunicipal bulk water system are discarded in in the logarithmic transformation.

Table 6.3: Definition of the variables used for the wastewater drainage and treatment cost function

Variable	Definition
TC^{WW}	Total cost of wastewater drainage and treatment (€/year)
Y^{WW}	Volume of wastewater collected (m^3/year)
C^{WW}	Number of customers of the wastewater service
P_L^{WW}	Labour price index in wastewater drainage and treatment (€/m^3 of water collected)
P_B^{WW}	Bulk wastewater collection price (€/m^3)
$P_K^{WW} = P_K^{WS}$	Price of capital (harmonized long-term interest rates for convergence assessment purposes) (%)
P_{OT}^{WW}	Price index for other miscellaneous inputs in wastewater service, including energy (€/m^3)
multimunicipalWW	Existence of a multimunicipal bulk water provider for the municipality
customerdensityWW	C^{WW}/area of the municipalities served (customers/km^2)
S_L^{WW}	Share of labour costs in total costs of wastewater drainage and treatment
S_B^{WW}	Share of bulk water acquisition costs in total costs of wastewater drainage and treatment
S_K	Share of capital costs in total costs of wastewater drainage and treatment
S_{OT}^{WW}	Share of costs with other miscellaneous inputs, including energy, in wastewater drainage and treatment

Table 6.4: Summary statistics of the variables used in the wastewater drainage and treatment cost function - all wastewater utilities

Variable	N	Mean	Std. Dev.	Min.	Max.
TC^{WW}	542	1,504,902	3,209,920	1,989	2.47×10^7
Y^{WW}	546	1,633,302	4,276,020	4,846	5.27×10^7
C^{WW}	503	13,439	26,303	260	182,466
L^{WW}	296	85,434	105,199	200	796,770
P_L^{WW}	166	0.263	0.471	0.007	5.080
P_B^{WW}	283	0.422	0.113	0	0.53
P_K^{WW}	550	3.955	0.496	3.46	4.45
P_{OT}^{WW}	469	0.520	1.129	0.000	14.633
multimunicipalWW	550	0.502	0.500	0	1
area	550	326.8	286.2	7.9	1,720.6
customerdensityWW	503	111.0	349.4	0.948	3,624.9
S_L^{WW}	167	0.183	0.132	0.006	0.602
S_B^{WW}	542	0.029	0.093	0.000	0.707
S_K	541	0.253	0.253	0.002	1.000
S_{OT}^{WW}	474	0.198	0.198	0.000	0.962

Tables 6.5 and 6.6 show the definition of the main variables used in the cost function model combining the water supply and wastewater collection activity and some summary statistics. Due to limitations in the number of complete observations available and the large number of parameters to be estimated in a translog equation, we have to dispose of the water losses variable. The price variables for labour and the residual cost category are obtained dividing their respective costs by the sum of the volumes of delivered water and wastewater collected. The bulk price is a simple average of the unit prices for bulk water supply and bulk wastewater collection. The cost shares consider the sum of the water supply and wastewater drainage and treatment activities. Populational density is used as a proxy for the number of customers of each utility[31].

Table 6.5: Definition of the variables used for the multi-output water and wastewater cost function

Variable	**Definition**
TC	Total cost of water supply and wastewater drainage and treatment (€/year)
Y^{WS}	Volume of water delivered (m^3/year)
Y^{WW}	Volume of wastewater collected (m^3/year)
C^{WS}	Number of water supply customers
C^{WW}	Number of customers of the wastewater service
P_L	Labour price index in water supply and wastewater drainage and treatment (€/m^3 of water collected)
P_B	Average of bulk water supply and bulk wastewater collection price (€/m^3)
$P_K = P_K^{WS} = P_K^{WW}$	Price of capital (harmonized long-term interest rates for convergence assessment purposes) (%)
P_{OT}	Price index for other miscellaneous inputs in water supply and wastewater service, including energy (€/m^3)
multimunicipalWS	Existence of a multimunicipal bulk water provider for the municipality
multimunicipalWW	Existence of a multimunicipal bulk water provider for the municipality
popdensity	population density(habitants/km^2)
S_L	Share of labour costs in total costs of wastewater drainage and treatment
S_B	Share of bulk water acquisition and bulk wastewater disposal costs in total costs of wastewater drainage and treatment
S_K	Share of capital costs in total costs of wastewater drainage and treatment
S_{OT}	Share of costs with other miscellaneous inputs, including energy, in wastewater drainage and treatment

[31] The simultaneous introduction of customer density measures for both water supply and wastewater would generate serious multicollinearity problems.

Table 6.6: Summary statistics of the variables used in the multi-output water and wastewater cost function - all water and wastewater utilities

Variable	N	Mean	Std. Dev.	Min.	Max.
TC	559	3,771,353	8,224,195	12,534	7.00×10^7
Y^{WS}	578	1,948,631	4,643,961	0	6.56×10^7
Y^{WW}	574	1,553,629	4,185,077	0	5.27×10^7
C^{WS}	568	15,747	31,265	0	341,799
C^{WW}	561	12,731	25,776	0	182,466
P_L	153	0.247	0.207	0.020	1.593
P_B	276	0.430	0.096	0	0.788
P_K	578	3.955	0.496	3.46	4.45
P_{OT}	489	0.391	0.463	0.002	4.083
multimunicipalWS	578	0.612	0.488	0	1
multimunicipalWW	568	0.509	0.500	0	1
popdensity	578	287.1	782.4	5.8	6498.4
S_L	152	0.196	0.124	0.013	0.607
S_B	559	0.076	0.140	0.000	0.773
S_K	558	0.371	0.196	0.013	1.000
S_{OT}	491	0.242	0.180	0.000	0.891

6.5 Empirical results - Economies of scale for water supply

Table 6.7 shows the estimated values for the parameters of the translog equation (6.1). All first-order coefficients for outputs and input prices have the expected positive sign, although the number of customers and the labour price are not significantly different from zero. Customer density also has the expected negative impact on total costs. Using the interpretation of the first order coefficients as cost elasticities at the sample mean, we can see that producing one percent more of water delivered costs increases total costs in 0.78%, while one percent more of water lost in the system increases total costs by only 0.2%. These values are close to the ones reported by Garcia and Thomas (2001) for the French region of Bordeaux, which were respectively 0.65% and 0.22%. They interpret this result as a confirmation of "the intuition that minimizing water losses is not a priority, especially if repairing leaks is very costly". This may be the case from the point of view of the water utility, specially if it is not paying the actual opportunity/scarcity cost of the water abstracted but it does not mean that for society as a whole it is better not to invest in the maintenance of the networks, because the price of water does not reflect its actual value[32]. The interpretation of coefficients as cost-elasticities at the sample mean is also useful to calculate the measure of economies of scale as the proportional increase in total costs resulting from proportional increases in both outputs and customers.

[32] We also stress that the interpretation of the cost-elasticity regarding water losses is not so straighforward, because the impacts that this undesirable output has on costs are twofold and opposed. On one hand a higher volume of water losses increases the costs of obtaining raw water from own sources or from bulk water purchases. On the other hand, higher values of water losses are incurred by utilities which save on outlays for network maintenance. These opposing effects alone may justify the lower coefficient.

Table 6.7: Translog parameter estimates for the water supply cost function

Parameter	**Estimate (Std. Error)**	**Parameter**	**Estimate (Std. Error)**
α_0	-0.394** (0.182)	$\alpha_{Y delivered,OT}$	0.060 (0.125)
$\alpha_{Y delivered}$	0.775** (0.338)	$\alpha_{Y losses,C}$	-0.087 (0.312)
$\alpha_{Y losses}$	0.199** (0.092)	$\alpha_{Y losses,L}$	0.105** (0.048)
α_C	0.110 (0.321)	$\alpha_{Y losses,B}$	0.219*** (0.071)
α_L	0.077 (0.061)	$\alpha_{Y losses,OT}$	-0.077*** (0.031)
α_B	0.345*** (0.122)	α_{CL}	-0.113 (0.136)
α_{OT}	0.684*** (0.055)	α_{CB}	-0.869*** (0.270)
$\frac{1}{2}\alpha_{Y delivered^2}$	-0.127 (0.494)	$\alpha_{C,OT}$	0.030 (0.142)
$\frac{1}{2}\alpha_{Y losses^2}$	-0.017 (0.023)	α_{LB}	-0.176*** (0.056)
$\frac{1}{2}\alpha_{CC}$	0.068 (0.639)	$\alpha_{L,OT}$	-0.102*** (0.021)
$\frac{1}{2}\alpha_{LL}$	0.481*** (0.053)	$\alpha_{B,OT}$	-0.092** (0.044)
$\frac{1}{2}\alpha_{BB}$	0.123 (0.081)	$\alpha_{Z customer density WS}$	-0.021 (0.059)
$\frac{1}{2}\alpha_{OT,OT}$	0.169*** (0.016)	$\alpha_{D-multimunicipal WS}$	0.384* (0.135)
$\alpha_{Y delivered,losses}$	0.196 (0.241)	$\alpha_{D-Algarve}$	0.195 (0.159)
$\alpha_{Y delivered,C}$	0.161 (1.084)	$\alpha_{D-Centro}$	0.049 (0.150)
$\alpha_{Y delivered,L}$	0.043 (0.126)	$\alpha_{D-Lisboa}$	-0.099 (0.238)
$\alpha_{Y delivered,B}$	0.727*** (0.245)	$\alpha_{D-Norte}$	0.057 (0.173)

*** Significance at the 0.01 level

** Significance at the 0.05 level

* Significance at the 0.10 level

Economies of output density measure the reciprocal of the percentage increase in total costs when output increases 1%, holding all other factors constant (the number of customers, the length of the distribution network and the input prices, namely). This measure of cost economies is relevant for output increases resulting from a higher demand from the existing customers. They are obtained by the following formula in our multi-output setting[33]:

$$EOD^{WS} = \frac{1}{\xi_{TC^{WS},Y^{WS}_{ldelivered}} + \xi_{TC^{WS},Y^{WS}_{losses}}} = \frac{1}{\frac{\partial \ln TC^{WS}}{\partial \ln Y^{WS}_{delivered}} + \frac{\partial \ln TC^{WS}}{\partial \ln Y^{WS}_{losses}}} \tag{6.7}$$

A value greater than one indicates that economies of output density exist, i.e., when the outputs increase in a given proportion (holding all other factors fixed) the costs increase in a lower proportion. We would talk about diseconomies of output density for values less than one. The computed value of 1.027 indicates that for the average water utility, an increased volume of output for the same number of customers would slightly decrease the average cost of production, as expected for a natural monopoly. The economies of customer density are obtained by[34]:

$$\begin{aligned} ECD^{WS} &= \frac{1}{\xi_{TC^{WS},Y^{WS}_{ldelivered}} + \xi_{TC^{WS},Y^{WS}_{losses}} + \xi_{TC^{WS},C^{WS}}} = \\ &= \frac{1}{\frac{\partial \ln TC^{WS}}{\partial \ln Y^{WS}_{delivered}} + \frac{\partial \ln TC^{WS}}{\partial \ln Y^{WS}_{losses}} + \frac{\partial \ln TC^{WS}}{\partial \ln C^{WS}}} \end{aligned} \tag{6.8}$$

Economies of customer density measure the reciprocal of the percentage increase in total costs when the number of customers and the volume outputs all increase 1%, holding all remaining factors fixed (network length, input prices). ECD differs from EOD only in the fact that increases in output results not from higher per customer demand but from an increase in the number of customers served. It may be a relevant measure for areas which are expanding their service coverage levels or with a growing population, but where the most of the distribution network is developed. From the results in table 6.7 we compute the value of 0.922, meaning that average costs would increase for the average

[33] See Nauges and Berg (2008*a*) for a multi-output case or Bottasso and Conti (2009) for a single-output example.

[34] The same formula could be used to obtain the returns on spatial density by considering the service area size in the place of the number of customers (Bottasso and Conti (2009)).

Portuguese water utility after a proportional increase in the number of customers and the corresponding outputs (a situation of diseconomies of customer density).

The formula for the economies of scale, had we considered the network length would be:

$$\begin{aligned} ES^{WS} &= \frac{1}{\xi_{TC^{WS},Y^{WS}_{ldelivered}}+\xi_{TC^{WS},Y^{WS}_{losses}}+\xi_{TC^{WS},C^{WS}}+\xi_{TC^{WS},length}} = \\ &= \frac{1}{\frac{\partial \ln TC^{WS}}{\partial \ln Y^{WS}_{delivered}}+\frac{\partial \ln TC^{WS}}{\partial \ln Y^{WS}_{losses}}+\frac{\partial \ln TC^{WS}}{\partial \ln C^{WS}}+\frac{\partial \ln TC^{WS}}{\partial \ln length}} \end{aligned} \tag{6.9}$$

The formula measures the reciprocal of the percentage increase in costs that would be associated with an increase of 1% in both outputs, number of customers and the network length and is especially relevant to analyse the advantages or disadvantages of merging neighbouring systems. A value of ES^{WS} greater than one would mean the existence of economies of scale, while a value less than one would signify a situation of diseconomies of scale. Because the length of the distribution network was not considered in our model, the economies of scale are given by the the returns on customer density. We conclude that the average Portuguese water utility is not undersized, which is in contrast with the result from Martins et al. (2008) which reports positive economies of scale for the industry average in Portugal. One possible explanation may be the fact that Martins et al. (2008) does not consider the number of customers given that we do find economies of output density for the sample average. We must stress that our result not mean that smaller units could not benefit from increasing their size of operations. Martins et al. (2008) shows that smaller utilities have larger economies of scale to be seized than larger operators.

In a multiple-output context, product-specific economies of scale can be obtained with the formulas (Panzar and Willig (1977))[35]:

$$ES_q = \frac{AIC_q^{WS}}{MC_q^{WS}} = \frac{IC_q^{WS}}{Y_q^{WS}MC_q^{WS}} = \frac{IC_q^{WS}}{\xi_{TC^{WS},Y_q^{WS}}TC^{WS}} = \frac{IC_q^{WS}}{\frac{\partial \ln TC^{WS}}{\partial \ln Y_q^{WS}}TC^{WS}} \tag{6.10}$$

$$MC_q = \frac{\partial TC^{WS}}{\partial Y_q^{WS}} \tag{6.11}$$

$$AIC_q = \frac{IC_q^{WS}}{Y_q^{WS}} \tag{6.12}$$

[35] See also Kim (1987) or Martins et al. (2008) for an explanation focused on the water industry.

$$IC_q^{WS} = TC^{WS} - TC_{-q}^{WS} \tag{6.13}$$

$$TC_{-q}^{WS} = TC^{WS}|_{Y_q^{WS}=0} \tag{6.14}$$

TC_{-q}^{WS} is the cost of producing all outputs except output q ($q = 0$) (Fraquelli et al. (2004)). IC_q^{WS} is the incremental cost of producing the output q while keeping the other outputs constant (for a given level of q it is computed as the difference between the costs for that level and the costs for $q = 0$). Product-specific economies of scale measure how would total costs change, given an increase in one of the outputs (q), keeping the other ones constant, as well as all other explanatory variables. This measure may be important because one of the products in our framework is not a real output, but rather a waste of water resources through leaks in the water distribution network or unmetered and unbilled water exits from the system. A "desirable" increase in scale could not only be one that increased proportionally the amount of water delivered and of water losses, but one that at least contained water losses at their present level while increasing the actual output. The formula in equation (6.14), however implies the consideration of null values for the other output, for which the translog function is not defined. We follow the approach of Kim (1987) and estimate stand alone total costs based on arbitrarily small values of outputs[36]. Because the estimation of equation (6.1) implied discarding a significant number of observations and the calculation of product-specific economies of scale will use sample averages from the several variables used[37], we present in table 6.8 the summary statistics for the observations actually used in estimating equation (6.1). This are the values used for the following calculations and not the industry averages from table 6.2.

Because we are dealing with mean-scaled variable, at the sample average values, all logarithms are null and total estimated cost can be obtained with following formula:

$$\ln\left(TC_{it}^{WS}\right) = \alpha_0 + \sum_n \alpha_{Dn} D_{it} \tag{6.15}$$

[36] We use the value of 10% of the industry average as proposed by Kim (1987).

[37] The mean showned in table 6.2 is for all mainland Portuguese water utilities with available information, while our estimation only considered those with complete information and most importantly, those which either had a multimunicipal bulk water provider available or that bought bulk water from a neighbouring municipality. We must therefore use the average of the sample considered in obtaining the results in table 6.7 and not the entire set of Portuguese water utilities.

Table 6.8: Summary statistics of the variables used in the water supply cost function - utilities with complete information

Variable	N	Mean	Std. Dev.	Min.	Max.
TC^{WS}	91	5,325,730	9,086,914	109,443	5.23×10^{7}
$Y^{WS}_{delivered}$	91	3,838,724	5,630,690	109,133	$2{,}31\times10^{7}$
Y^{WS}_{losses}	91	1,853,484	2,646,706	5,000	$1{,}38\times10^{7}$
C^{WS}	91	29,778	43,030	1,450	182,466
P^{WS}_{L}	91	0.220	0.163	0.006	0.797
P^{WS}_{B}	91	0.396	0.145	0.62	1.12
P_{K}	91	3.993	0.469	3.46	4.45
P^{WS}_{OT}	91	0.548	0.493	0.003	2.402
multimunicipalWS	91	0.868	0.340	0	1
area	91	311.6	308.5	7.9	1,720.6
customerdensityWS	91	221.0	506.6	2.7	3,698.5
S^{WS}_{L}	91	0.163	0.120	0.006	0.608
S^{WS}_{B}	91	0.235	0.228	0.000	0.849
S_{K}	91	0.256	0.180	0.005	0.708
S^{WS}_{OT}	91	0.327	0.192	0.002	0.721

The corresponding total cost of producing only one of the output (TC^{WS}_{-q}) is given by:

$$\ln\left(TC^{WS}_{it}\right) = \alpha_0 + \alpha_{Yq}\ln\left(Y^{WS}_{qit}\right) + \alpha_{Yq^2}\left(\ln\left(Y^{WS}_{qit}\right)\right)^2 + \sum_n \alpha_{Dn}D_{it} \tag{6.16}$$

where Y^{WS}_{qit} is 0.1 (10% of the sample average in our case) or other arbitrarily small value.

The values obtained for the product-specific economies are 4.90 and 8.81, respectively for water delivered and water losses. The former means that there would be significant returns to scale to be seized if the amount of water delivered could be increased while keeping water losses at a constant level. This may however not be a realistic assumption. The interpretation of the latter is not really useful[38].

So far, we have analyzed the situation regarding economies of scale and economies of output density for the sample average, but it is interesting to look at the results for the

[38] It would mean that, holding water delivered constant, water losses could be increased with a much less than proportional increase in costs, but although the specification of water losses as outputs has some advantages in the estimation of the cost function, we should be reminded that they are not associated with a corresponding revenue like water deliveries. The result may mean that it is cheap to let the water flow from open taps and leaks (probably due to the lack of a price for the resource itself rather than the provision service), but it certainly does not imply that is an economically good idea!

various values of water delivered, water losses and number of customers in the sample range (we continue to evaluate all other variables at the sample mean, including water losses). The general formulas for cost elasticities now become (continuing to consider sample averages for the remaining regressors like input prices):

$$\frac{\partial \ln TC^{WS}}{\partial \ln Y^{WS}_{delivered}} = \alpha_{Y\,delivered} + \alpha_{Y\,delivered^2} \ln \left(Y^{WS}_{deliveredit}\right) + \tag{6.17}$$
$$+\alpha_{Y\,delivered,losses} \ln \left(Y^{WS}_{lossesit}\right) + \alpha_{Y\,delivered,C} \ln \left(C^{WS}_{it}\right)$$

$$\frac{\partial \ln TC^{WS}}{\partial \ln Y^{WS}_{losses}} = \alpha_{Y\,losses} + \alpha_{Y\,losses^2} \ln \left(Y^{WS}_{lossesit}\right) + \tag{6.18}$$
$$+\alpha_{Y\,delivered,losses} \ln \left(Y^{WS}_{deliveredit}\right) + \alpha_{Y\,losses,C} \ln \left(C^{WS}_{it}\right)$$

$$\frac{\partial \ln TC^{WS}}{\partial \ln C^{WS}} = \alpha_C + \alpha_{CC} \ln \left(C^{WS}_{it}\right) + \tag{6.19}$$
$$+\alpha_{Y\,delivered,C} \ln \left(Y^{WS}_{deliveredit}\right) + \alpha_{Y\,losses,C} \ln \left(Y^{WS}_{lossesit}\right)$$

The estimated parameters from table 6.7 can be substituted in the formulas above and in equations (6.7) and (6.8) recalculated. The result is shown in Figures 6.1 and 6.2. In each of the graphics they contain, only one variable is allowed to vary[39], while all others are evaluated at the sample average. It is possible to see that economies of output density are increasing with the volume of water delivered, but decreasing with the amounts of water losses and the number of customers. The figures also show the previous result that for the industry at the sample average there are economies of output density[40].

On the contrary, from Figure 6.2 we confirm the result that the sample average utility is not enjoying economies of scale (proportionally increasing outputs and customers will increase its total costs more than proportionally). For values outside the sample averages we see that the a utility is more likely to be in a situation of economies of scale the larger the utility is, as measured by its customer base. The opposite happens regarding outputs which show a negative association with scale economies.

[39] The figures considered variations between one third and three times the sample average values for the variable, which is within the values used for estimation.

[40] The sample average of the x-axis variable is one, due to the mean-scaling transformation.

Figure 6.1: Economies of output density in water supply

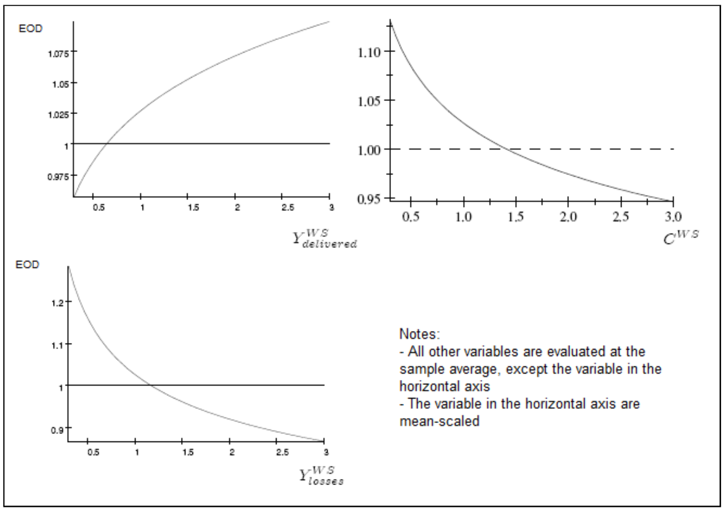
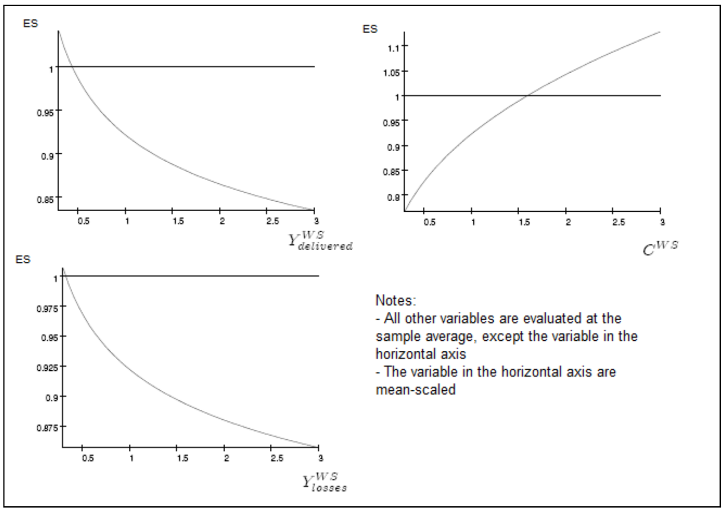


Figure 6.2: Economies of scale in water supply



The measure of economies of scale seems to be a more realistic measure than economies of output density as the volumes of water delivered , water losses and the number of customers are strongly associated. A simple correlation matrix between the three variables for all available observations shows this clearly (Table 6.9). It is therefore more useful to think of possible expansions based on increasing the three variables simultaneously[41]. The overall conclusion seems to be that the utility which would gain the most from increasing its size would be the one with a large customer base, but providing a smaller amount of water and with a reduced number of water losses. This seems to favour the expansion of efficient systems (with low leakage) with water conservation policies.

Table 6.9: Correlation matrix for water supply outputs and customers

	$Y^{WS}_{delivered}$	Y^{WS}_{losses}	C^{WS}
$Y^{WS}_{delivered}$	1.0000	-	-
Y^{WS}_{losses}	0.9192	1.0000	-
C^{WS}	0.9798	0.8829	1.0000

Because of this strong association between the output and customer variables we can follow a different approach and recalculate the measures of economies of output density and scale for different utility sizes, according to proportional variations in all three variables, water delivered, water losses and the number of customers[42]. The result is shown in Figure 6.3 for EOD^{WS} and in Figure 6.4 for ES^{WS}. The economies of output density exist for smaller utilities and persist at the sample average, while the diseconomies of scale exist for the entire existing range of utility size in Portugal, although they are reduced with size[43]. This impact of the size of utilities on the measures of scale elasticities is not common. It is more usual to find economies of scale which subside as we consider larger and larger utilities. Nevertheless, this result is not new and several other authors have reported values for economies of scale that are increasing with the utility size: Mizutani and Urakami (2001), Aubert and Reynaud (2005) (short-run), Torres and Paul (2006) and Bottasso and Conti (2009) report it for retail water supply, while Fraquelli et al. (2004) do it for a study of the joint production of water, gas and electricity.

[41] This is not incontradiction with the benefits that can be gained from measures to control water losses, but only to admit that they may have a limited impact.

[42] The procedure of analysing scale and scope economies for ray expansions and contractions of selected mean-scaled variables for average values of input prices is also followed by Fraquelli et al. (2004), for example.

[43] Because the translog specification used is a second-order Taylor series approximation with reference to the sample average, the quality of the approximation is naturally better for values closed to the mean.

Figure 6.3: Economies of output density in water supply for different utility sizes

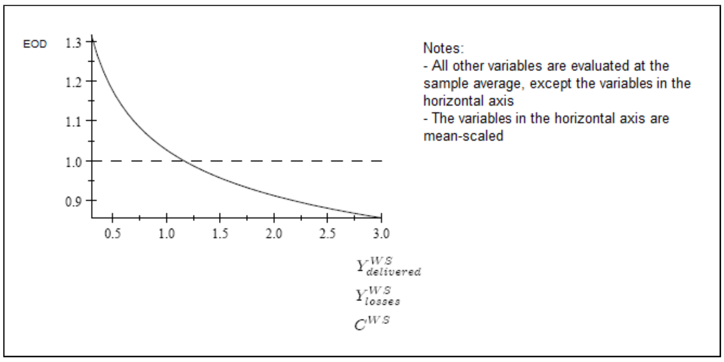
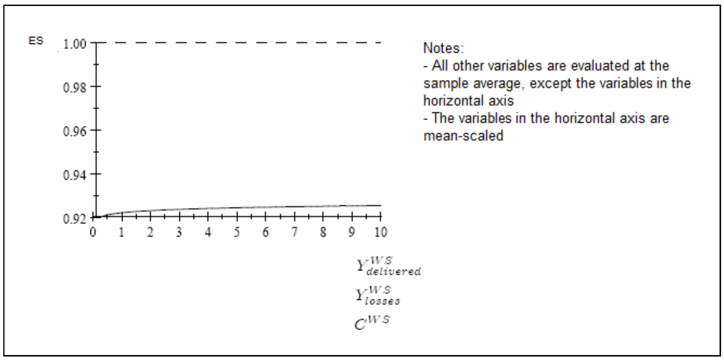


Figure 6.4: Economies of scale in water supply for different utility sizes



For multi-output cost functions a measure of economies of scope can be calculated, which, if greater than zero, indicates that costs savings can be made by the joint production of outputs rather than in separate. Equation (6.20) shows how they can be calculated in our framework for model (6.1).

$$SP^{WS} = \frac{\left(TC^{WS}|_{Y^{WS}_{delivered}=0} + TC^{WS}|_{Y^{WS}_{losses}=0}\right) - TC^{WS}}{TC^{WS}} \tag{6.20}$$

$SP^{WS} > 1 \Leftrightarrow TC^{WS}|_{Y^{WS}_{delivered}=0} + TC^{WS}|_{Y^{WS}_{losses}=0} > TC^{WS}$ means that the separate production of the two outputs ($Y^{WS}_{delivered}$ and Y^{WS}_{losses} in our case) is associated with greater costs than would be incurred by their joint production (TC^{WS}), so that economies of scope could be achieved. $SP^{WS} < 1$ would represent the presence of diseconomies of scope.

Garcia and Thomas (2001) and Martins et al. (2008) calculate measures of economies of scope for the joint production of drinking water and water losses in Bordeaux, France, and in Portugal respectively. For their sample averages they find significant economies of scope (0.2367 and 0.327). Our estimations show a different result, -0.338,[44] but our main interest is not so much in the interpretation of our result but in questioning the very point of estimating economies of scope for water losses. Garcia and Thomas (2001) do present some arguments and try to make a case for the interpretation of this measure in the context of water losses as comparing a situation where water supply is provided together with water losses (because repairing the leaks would be more costly than abstracting more water to satisfy demand) with a situation where water losses are contained and more water is "produced" from the investment in a more efficient distribution system. We question their point of view on two accounts. First, their measure of scope economies, being similar to our equation (6.20), is not comparing the joint production with producing only tap water (while keeping water losses at a minimum). It is instead comparing the former situation with another where the same amounts of tap water and water losses are produced by two separate utilities, one for each type of output (which is an unreal possibility). To truly follow their interpretation they would have to remove the $TC^{WS}|_{Y^{WS}_{delivered}=0}$ component from their measure of economies of scope and the resulting figure would necessarily be lower. Second, while the interpretation of water losses as an output seems reasonable, given that it is a result of the water supplying activity that adds to the costs incurred by the utility, the effect on costs of moving from producing two outputs to a single one (or vice-versa) is opposite to the traditional interpretation, because producing tap water without water losses is more expensive than producing it with them[45].

For aforementioned reasons we believe the measure of economies of scope to be inadequate to analyze the situation regarding water losses and think more information can be

[44] Because the formula in 6.20 implies the consideration of null values for the output, for which the translog function is not defined, we follow again the approach of Kim (1987) and estimate stand alone total costs based on arbitrarily small values of outputs (using the value of 10% of the industry average as proposed by Kim (1987)).

[45] Theoretically one can think of a high enough price for bulk water to invert this conclusion, but in practice, the bulk water is usually underpriced (by not including the scarcity cost of abstracting it) and retail operators often have alternative sources of surface and groundwater.

provided from the analysis of the third graphic in Figures 6.7 and 6.9, which show that for given values of water delivered and customers, economies of output density and economies of scale are more likely to happen the lower the level of water losses. In the end, the determination of the efficient amount of water losses requires cost-benefit analysis beyond the scope of this paper.

6.6 Empirical results - Economies of scale for wastewater drainage and treatment

We turn now to the analysis of the sewerage part of the Portuguese water industry. Table 6.10 presents the results from the estimation of equation (6.2). All the first-order coefficients for the outputs and input prices have the expected positive sign. The coefficient for customers has an unexpected negative sign, but it is not significantly different from zero[46]. The price per m^3 paid to bulk wastewater collectors, also does not appear to be a relevant explanatory factor for costs. Customer density does not seem to have a significant impact on costs. On the other hand, the existence of a bulk wastewater collector is strongly associated with larger costs, probably reflecting a greater compliance with legal standards for wastewater treatment.

Like in the case for water supply, the estimation results presented in table 6.10 had to be obtained with a number of available observations which is significantly lower than the total number of wastewater utilities, due to missing data and the inclusion of the bulk wastewater price. Table 6.11 presents the summary statistics for the used sample:

[46] One hypothesis could be that a smaller number of customers, for a given level of output would reflect a greater presence of large industrial businesses which would impose greater treatment costs on the system. Nevertheless, the negative sign is robust to the inclusion of the proportion of nonresidential customers, which turns out not to be a significant regressor as is not included in this final estimation. Other possible explanation could be that the number of customers would only include those which are connected to the public sewer network, but that larger costs would be incurred attending households with septic tanks.

Table 6.10: Translog parameter estimates for the wastewater drainage and treatment cost function

Parameter	Estimate (Std. Error)	Parameter	Estimate (Std. Error)
β_0	0.956*** (0.374)	$\beta_{Y,OT}$	0.098 (0.068)
β_Y	1.185*** (0.208)	β_{CL}	-0.051 (0.098)
β_C	-0.240 (0.203)	β_{CB}	0.152 (0.221)
β_L	0.499*** (0.111)	$\beta_{C,OT}$	-0.054 (0.079)
β_B	0.324 (0.254)	$\beta_{L,B}$	-0.008 (0.095)
β_{OT}	0.642*** (0.075)	$\beta_{L,OT}$	-0.062** (0.029)
$\frac{1}{2}\beta_{YY}$	0.161* (0.085)	$\beta_{B,OT}$	0.050 (0.073)
$\frac{1}{2}\beta_{CC}$	0.128 (0.120)	$\beta_{Zcustomerdensity WW}$	0.072 (0.459)
$\frac{1}{2}\beta_{LL}$	0.149*** (0.034)	$\beta_{D-multimunicipal WW}$	0.956*** (0.373)
$\frac{1}{2}\beta_{BB}$	0.142 (0.199)	$\beta_{D-Algarve}$	-0.141 (0.315)
$\frac{1}{2}\beta_{OT,OT}$	0.070*** (0.011)	$\beta_{D-Centro}$	-0.095 (0.225)
β_{YC}	-0.272 (0.177)	$\beta_{D-Lisboa}$	0.059 (0.383)
β_{YL}	0.075 (0.084)	$\beta_{D-Norte}$	-0.091 (0.270)
β_{YB}	-0.013 (0.198)		

*** Significance at the 0.01 level

** Significance at the 0.05 level

* Significance at the 0.10 level

Table 6.11: Summary statistics of the variables used in the wastewater drainage and treatment cost function - utilities with complete information

Variable	N	Mean	Std. Dev.	Min.	Max.
TC^{WW}	66	3,499,454	5,578,848	114,415	2.43×10^7
Y^{WW}	66	3,876,389	7,988,708	36,000	5,27×10^7
C^{WW}	66	27,652	43,417	693	182,466
P_L^{WW}	66	0.280	0.375	0.007	2.150
P_B^{WW}	66	0.406	0.117	0.08	0.53
P_{OT}^{WW}	66	0.682	0.852	0.00	4.34
multimunicipalWW	66	0.939	0.240	0	1
area	66	270.3	237.2	26.7	1,438.2
customerdensityWW	66	188.7	412.5	4.1	2,457.8
S_L^{WW}	66	0.154	0.111	0.006	0.409
S_B^{WW}	66	0.119	0.172	0.000	0.707
S_K	66	0.379	0.231	0.011	0.925
S_{OT}^{WW}	66	0.323	0.227	0.001	0.962

The previous formulas for the calculation of economies of output density and economies of scale (equal to economies of customer density in our framework) are adapted to the wastewater context and to the single output cost function (6.2) in the following formulas:

$$EOD^{WW} = \frac{1}{\frac{\partial \ln TC^{WW}}{\partial \ln Y^{WW}}} \tag{6.21}$$

$$ES^{WW} = ECD^{WW} = \frac{1}{\frac{\partial \ln TC^{WW}}{\partial \ln Y^{WW}} + \frac{\partial \ln TC^{WW}}{\partial \ln C^{WW}}} \tag{6.22}$$

The computed values for the sample averages are 0.84 and 1.06, respectively for the economies of output density and for the economies of scale. Increasing the volume of wastewater collected for the same number of customers would bring about a more than proportional increase in costs, while if the increased activity was the result of an increased number of customers, the opposite would happen and economies of scale would be achieved. The result seems to be the opposite to the one obtained for the water supply side of the industry.

Next we repeat the previous procedure of considering values for the output and the number of customers other than the sample averages. The general formulas for cost elasticities in the sewerage industry become (continuing to consider sample averages for the remaining regressors like input prices):

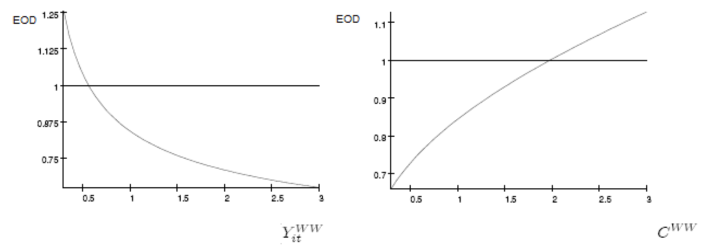
$$\frac{\partial \ln TC^{WW}}{\partial \ln Y^{WW}} = \beta_Y + \beta_{YY} \ln \left(Y_{it}^{WW}\right) + \beta_{YC} \ln \left(C_{it}^{WW}\right) \tag{6.23}$$

$$\frac{\partial \ln TC^{WW}}{\partial \ln C^{WW}} = \beta_C + \beta_{CC} \ln \left(C_{it}^{WW}\right) + \beta_{YC} \ln \left(Y_{it}^{WW}\right) \tag{6.24}$$

The estimated parameters from table 6.10 are substituted in the formulas (6.23), (6.24), (6.21) and (6.22) are recalculated. The result is shown in Figures 6.5 and 6.6. For the sample average values, one can confirm the inexistence of economies of output density. This type of economies is more likely to appear for utilities with larger customer bases or with smaller output levels.

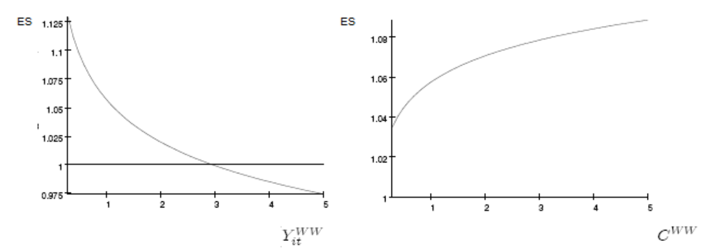
Once again, we should remind ourselves that the previous measure considers the economies to be had if we increase output, while keeping all other factors fixed, which is not exactly a realistic situation (the correlation between the volumes collected and the number of customers is 0.8428 for the Portuguese industry). It is better to think of the effect on costs of a proportional increase in customers and outputs, which would result, for example, from merging the water/wastewater utilities of two or more neighboring municipalities. Figure 6.6 shows the existence of economies of scale for the sample average and the fact that they decrease with the amount of wastewater collected, but increase with the number of customers. The overall conclusion is similar to the one found for water supply: the utilities with larger customer bases and lower amounts of wastewater collected are the ones that enjoy the highest economies of scale. Because the amount of water delivered and the amount of wastewater collected are strongly associated (the correlation coefficient is 0.97 for our data), we draw the same conclusion that economies of scale seem to be found in larger and more efficient systems.

Figure 6.5: Economies of output density in wastewater drainage and treatment



Notes:
- All other variables are evaluated at the sample average, except the variable in the horizontal axis
- The variables in the horizontal axis are mean scaled

Figure 6.6: Economies of scale in wastewater drainage and treatment



Notes:
- All other variables are evaluated at the sample average, except the variable in the horizontal axis
- The variables in the horizontal axis are mean scaled

Figures 6.7 and 6.8 show the calculation of EOD^{WW} and ES^{WW} for different utility sizes, considering the more realistic assumption of proportional variations in both the volume of sewage collected and the number of customers. They confirm the result that diseconomies of output density do exist for the virtually all the significant range of possible actual utility sizes, but that economies of scale can be seized up to a size which is about five times larger than the sample average.

Figure 6.7: Economies of output density in wastewater drainage and treatment for different utility sizes

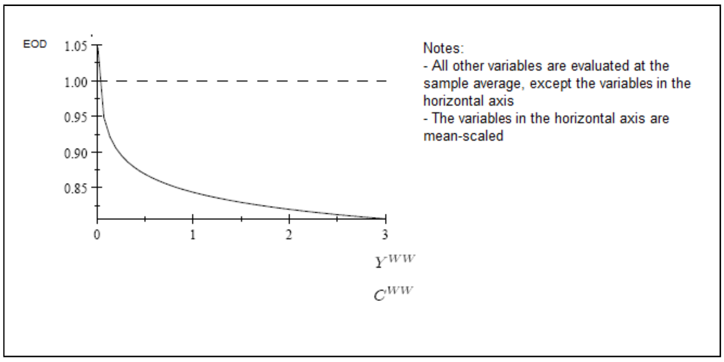
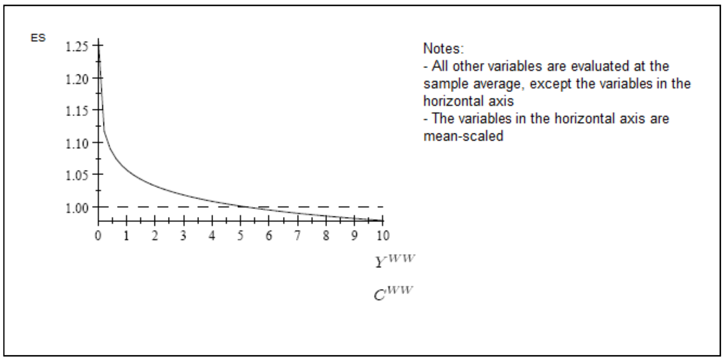


Figure 6.8: Economies of scale in wastewater drainage and treatment for different utility sizes



6.7 Economies of scale and scope with a multi-output cost function for water supply and wastewater drainage and treatment

For mainland Portugal, for 260 out of 278 municipalities there is a single utility combining the services of water supply and wastewater drainage and treatment. The analysis of the industry's costs for the retail level would not be complete without an analysis of the economies of scope between these two different but so often associated activities. This is accomplished through the estimation of model (6.3) with the same methodology described for the previous estimations. A complete specification of outputs would include not only the amount of water delivered and wastewater collected but also the volume of water losses in the same way as we did in section 6.5. However, the limited number of available observations with complete information, prevented us from using all three outputs, as the number of parameters to be estimated tends to increase exponentially with the translog and would overcome the number of available observations. Our choice is to discard the water losses variable and keep a symmetrical situation between both activities[47]. Table 6.12 presents the estimation results. The coefficients for outputs, customers and input prices are positive as expected with the exception of the volume of wastewater collected which comes up with a negative sign, but which is not significantly different from zero. The impact of the number of customers is also not significantly different from zero as in the previous estimations, the same happening with the coefficient for the price for bulk transactions[48].

[47]Because combined sewer systems (conveying both storm water and sanitary sewage) or only partially separated sewer systems represent between 65% and 75% of all collecting systems (Roseta-Palma et al. (2006)), leaving out water losses from the estimation is equivalent to the disregarding of storm water (or groundwater) infiltrations and its consequences on the costs of wastewater treatment. Although the consideration of water losses has been slowly making its way into the estimation of the water supply cost function (see Fraquelli and Moiso (2005), Lin (2005) and Garcia and Thomas (2001) for three different ways to consider water losses), no study so far was able to use a measure of infiltration in the sewer system.

[48]In the previous estimations, bulk water price proved to have a significant impact on the costs of water supply while the price for bulk wastewater collection did not. Due to the limitation in the number of available obsevations we choose to average both prices here.

Table 6.12: Translog parameter estimates for the multi-output water supply and wastewater drainage and treatment cost function

Parameter	Estimate (Std. Error)	Parameter	Estimate (Std. Error)
γ_0	0.223 (0.589)	$\gamma_{YCcollected^2}$	0.319 (0.291)
$\gamma_{Ydelivered}$	1.172** (0.543)	$\gamma_{Ycollected,L}$	0.079 (0.124)
$\gamma_{Ycollected}$	-0.351 (0.371)	$\gamma_{Ycollected,B}$	-0.092 (0.298)
$\gamma_{Cdelivered}$	0.200 (0.604)	$\gamma_{Ycollected,OT}$	0.010 (0.128)
$\gamma_{Ccollected}$	0.137 (0.403)	$\gamma_{Cdelivered,collected}$	0.827 (1.094)
γ_L	0.503*** (0.140)	$\gamma_{Cdelivered,L}$	-0.219 (0.274)
γ_B	0.160 (0.272)	$\gamma_{Cdelivered,B}$	-0.558 (0.625)
γ_{OT}	0.687*** (0.095)	$\gamma_{Cdelivered,OT}$	-0.003 (0.292)
$\frac{1}{2}\gamma_{Ydelivered^2}$	0.739 (0.751)	$\gamma_{Ccollected,L}$	0.121 (0.130)
$\frac{1}{2}\gamma_{Ycollected^2}$	-0.324 (0.224)	$\gamma_{Ccollected,B}$	0.207 (0.309)
$\frac{1}{2}\gamma_{Cdelivered^2}$	0.210 (1.653)	$\gamma_{Ccollected,OT}$	-0.074 (0.137)
$\frac{1}{2}\gamma_{Ccollected^2}$	-0.372 (0.318)	γ_{LB}	-0.209* (0.110)
$\frac{1}{2}\gamma_{LL}$	0.340*** (0.065)	$\gamma_{L,OT}$	-0.154*** (0.040)
$\frac{1}{2}\gamma_{BB}$	0.057 (0.303)	$\gamma_{B,OT}$	0.020 (0.094)
$\frac{1}{2}\gamma_{OT,OT}$	0.141*** (0.027)	$\alpha_{ZpopdensityWS}$	-0.052 (0.099)
$\gamma_{Ydelivered,collected}$	0.327 (0.560)	$\alpha_{D-multimunicipalWS}$	0.012 (0.396)
$\gamma_{YCdelivered^2}$	-1.486 (2.175)	$\alpha_{D-multimunicipalWW}$	-0.156 (0.329)
$\gamma_{YCdelivered,collected}$	-0.260 (0.819)	$\alpha_{D-Algarve}$	0.247 (0.341)
$\gamma_{Ydelivered,L}$	-0.018 (0.248)	$\alpha_{D-Centro}$	-0.033 (0.251)
$\gamma_{Ydelivered,B}$	0.502 (0.573)	$\alpha_{D-Lisboa}$	-0.119 (0.491)
$\gamma_{Ydelivered,OT}$	0.109 (0.257)	$\alpha_{D-Norte}$	-0.308 (0.300)
$\gamma_{YCcollected,delivered}$	dropped		

*** Significance at the 0.01 level

** Significance at the 0.05 level

* Significance at the 0.10 level

Like the previous estimations, the estimation results presented in table 6.12 were obtained with a limited sample of observations with complete information. Table 6.13 presents the summary statistics for the used sample.

Table 6.13: Summary statistics of the variables used in the multi-output water supply and wastewater drainage and treatment cost function - utilities with complete information

Variable	**N**	**Mean**	**Std. Dev.**	**Min.**	**Max.**
TC	51	8,274,942	1.39×10^7	354,916	$5{,}94\times10^7$
Y^{WS}	51	3,630,971	5,749,652	149,608	2.31×10^7
Y^{WW}	51	2,997,787	4,985,804	36,000	2.48×10^7
C^{WS}	51	28,501	43,500	2,007	182,466
C^{WW}	51	25,308	43,994	693	182,466
P_L	51	0.235	0.169	0.027	0.834
P_B	51	0.412	0.119	0.170	0.788
P_K	51	3.926	0.499	3.46	4.45
P_{OT}	51	0.532	0.421	0.006	1.763
multimunicipalWS	51	0.941	0.238	0	1
multimunicipalWW	51	0.961	0.196	0	1
popdensity	51	345.0	765.5	11.2	4917.0
S_L	51	0.163	0.098	0.026	0.436
S_B	51	0.182	0.193	0.000	0.733
S_K	51	0.295	0.180	0.013	0.724
S_{OT}	51	0.344	0.194	0.003	0.807

The formulas for the economies of output/production density and for the economies of scale given by equations (6.7) and (6.9) are now, respectively (Garcia and Thomas (2001)):

$$EOD = \frac{1}{\frac{\partial \ln TC}{\partial \ln Y_{delivered}} + \frac{\partial \ln TC}{\partial \ln Y_{collected}}} \tag{6.25}$$

$$ES = ECD = \frac{1}{\frac{\partial \ln TC}{\partial \ln Y_{delivered}} + \frac{\partial \ln TC}{\partial \ln Y_{collected}} + \frac{\partial \ln TC}{\partial \ln C_{delivered}} + \frac{\partial \ln TC}{\partial \ln C_{collected}}} \tag{6.26}$$

The computed values at the sample average are 1.22 for the economies of output density and 0.86 for the economies of scale, implying that average costs would decrease for increased output volumes for the same number of customers, but they rise for proportional increases in customers and volumes. This results are shown in Figures 6.9 and 6.10, which portray them for different utility sizes, as measured by proportional variations in both the outputs and the customers of both water supply and wastewater drainage and treatment.

For the existing ranges of utility sizes in our sample we find economies of output density, which are larger for smaller utilities and diseconomies of scale, which are smaller for larger utilities.

Figure 6.9: Economies of output density for the multi-output water supply wastewater drainage and treatment cost function for different utility sizes

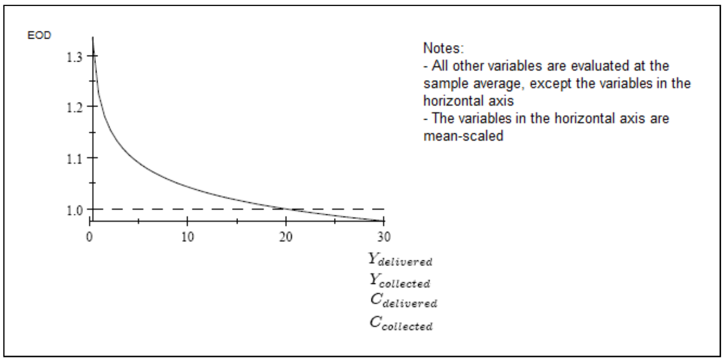
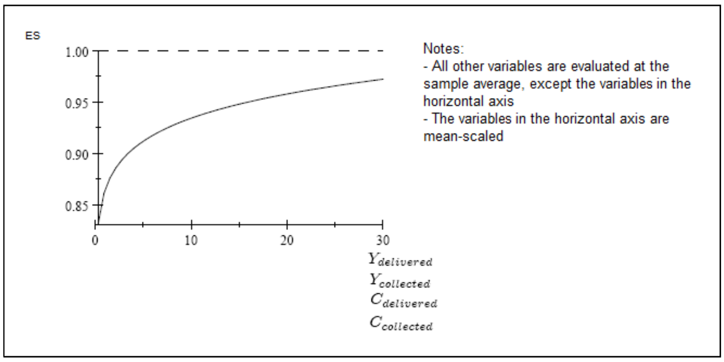


Figure 6.10: Economies of scale for the multi-output water supply and wastewater drainage and treatment cost function for different utility sizes



The major reason for estimating a combined cost function for water supply and wastewater collection is the analysis of the benefits seized by the joint operation of both activities. The measure of the economies of scope is given by[49]:

$$SP = \frac{(TC|_{Y_{delivered}=0 \wedge C_{delivered}=0} + TC|_{Y_{collected}=0 \wedge C_{collected}=0}) - TC}{TC} \tag{6.27}$$

Because the formula in equation (6.14) implies the consideration of null values for the output, for which the translog function is not defined, we follow again the approach of Kim (1987) and estimate stand alone total costs based on arbitrarily small values of outputs and customers[50]. The value obtained of -0.78 indicates strong diseconomies of scope and is in contrast with the positive values previously estimated by Martins, Fortunato and Coelho (2006) for the average of the Portuguese water industry. One other result which is contrary to the evidence provided by Martins, Fortunato and Coelho (2006) is the fact that economies of scope seem to be exist for utilities with larger sizes in our results as can be seen from table 6.14. A positive impact of size on scope economies has also been found by Torres and Paul (2006) and Fraquelli et al. (2004) which report measures of economies of scope that decrease with size for smaller utilities, but which increase with size for the larger ones. There we present the results for the economies of scope measure for different selected utilities sizes, obtained by simultaneously considering different proportions regarding their respective sample averages for the outputs and customers' variables. For utilities with sizes which are three times or more larger than the sample average the combined management of the water supply and wastewater drainage and treatment is cheaper than their separate operation and the opposite happens for the smaller systems.

[49] The formulas presented by in the literature usually omit the number of customers (Garcia and Thomas (2001) and Fraquelli et al. (2004)), but the situation of producing a single output necessarily implies having only one type of customer.

[50] We use the value of 10% of the industry average as proposed by Kim (1987).

Table 6.14: Scope economies for different utility sizes

Proportion of the sample average (Y^{WS},Y^{WW},C^{WS},C^{WW})	**SP**
0.25	-0.72
0.50	-0.82
0.75	-0.81
1.00	-0.78
2.00	-0.47
3.00	0.18
4.00	1.34
5.00	3.30

Note: All variables are mean-scaled (1 = sample average size)

6.8 Conclusion

In this paper we have assessed the cost structure of the Portuguese water industry at the retail level, testing the existence of economies of scale and scope, at a time when public water infrastructure investments policies in Portugal seem to be most concerned with achieving these cost economies. This is the first study to jointly consider the water and wastewater activities in the Portuguese water industry while accounting for the input prices. It also differs from previous estimations of cost functions for the Portuguese industry by using the estimation method and functional form most widely applied in the literature, respectively the estimation of seemingly unrelated regression equation on a translog specification.

Our results differ from previous research for the Portuguese water industry in that for the sample average we find diseconomies of scale for water supply and for utilities combining the water supply and wastewater drainage and treatment activities (even with evidence of economies of output density for the sample average). For wastewater sewerage we do find evidence of economies of scale for the sample average. Our results are also contrasting in that economies of scale are found to increase with the size of the utility, except for wastewater collection.

Regarding economies of scope, we question previous interpretations of this measure on multi-output cost functions for water delivered and water losses. We find that the reduction of water losses favours the existence of economies of scale. Diseconomies of scope are found for the combined activities of water supply and wastewater drainage and treatment, but the situation improves with the utility size and for utilities larger than three times the sample average economies of scope do exist.

Future research should seek to improve the data on the length of the distribution network and the input price variables in order to be able to distinguish short-run from long-run cost-elasticities and to improve the efficiency of the estimates. The effects of ownership on costs and efficiency levels could be tested and the analysis could be extended to bulk water providers / wastewater collectors. The present findings and methods could also be applied in combination with the estimation of the demand for water to assess the impacts on welfare from adopting distinct water tariff schedules.

Appendix A

Derivation of equation 4.16

This Appendix contains the derivation of equation (4.16). See also (Brown and Sibley (1986, pp.205-6)).

Proof. $(1+\lambda)\left(\frac{\partial B}{\partial w}-\frac{\partial C}{\partial w}\right)g(\theta)-\lambda\frac{\partial^2 B}{\partial w\partial\theta}(1-G(\theta))-\mu g(\theta)=0$

since $\frac{\partial B(w,\theta,\phi)}{\partial w}=\frac{dP}{dw}\equiv p_m$

$\Leftrightarrow (1+\lambda)\left(p_m-\frac{\partial C}{\partial w}\right)g(\theta)-\mu g(\theta)=\lambda\frac{\partial^2 B}{\partial w\partial\theta}(1-G(\theta))\Leftrightarrow$

$\Leftrightarrow \dfrac{p_m-\left(\frac{\partial C}{\partial w}+\frac{\mu}{1+\lambda}\right)}{p_m}=\frac{\lambda}{1+\lambda}\frac{1}{p_m}\frac{\partial^2 B}{\partial w\partial\theta}\frac{(1-G(\theta))}{g(\theta)}\Leftrightarrow$

$\Leftrightarrow \dfrac{p_m-\left(\frac{\partial C}{\partial w}+\frac{\mu}{1+\lambda}\right)}{p_m}=\frac{\lambda}{1+\lambda}\frac{1}{p_m}\dfrac{1}{\dfrac{\partial\underline{\theta}}{\partial p_m}}\frac{(1-G(\theta))}{g(\theta)}\Leftrightarrow$

where $\underline{\theta}$ indicates the marginal consumer group ($\underline{\theta}=\underline{\theta}\left(Q,P\left(Q\right)\right)$)

Defining marginal willingness to pay, $\rho\left(w,\theta\right)$, the self-selection condition is $\rho\left(w,\underline{\theta}\right)=p_m$,so that $\dfrac{d\rho}{dp_m}=1\Leftrightarrow\dfrac{\partial\rho}{\partial\underline{\theta}}\dfrac{\partial\underline{\theta}}{\partial p_m}=1\Leftrightarrow\dfrac{\partial\underline{\theta}}{\partial p_m}\rho_\theta=1\Leftrightarrow\dfrac{\partial\underline{\theta}}{\partial p_m}=\dfrac{1}{\rho_\theta}>0$

Since $B_{w\theta}\equiv\dfrac{\partial^2 B\left(w,\theta\right)}{\partial w\partial\theta}\equiv\rho_\theta\equiv\dfrac{\partial\rho\left(w,\theta\right)}{\partial\theta}$, $\dfrac{\partial\underline{\theta}}{\partial p_m}=\dfrac{1}{B_{\theta w}}$

Finally,

$\Leftrightarrow \dfrac{p_m-\left(\frac{\partial C}{\partial w}+\frac{\mu}{1+\lambda}\right)}{p_m}=\frac{\lambda}{1+\lambda}\dfrac{1}{p_m\dfrac{\partial\underline{\theta}}{\partial p_m}\dfrac{g\left(\theta\right)}{(1-G(\theta))}}\Leftrightarrow$

$\Leftrightarrow \dfrac{p_m-\left(\frac{\partial C}{\partial w}+\frac{\mu}{1+\lambda}\right)}{p_m}=\frac{\lambda}{1+\lambda}\dfrac{1}{\xi(w,p_m)}$

which is the condition in the text. $\xi(w,p_m)$ emerges through the following manipulations:

$$\frac{\partial \ln p_m(w)}{\partial p_m(w)} = \frac{1}{p_m(w)}$$

$$\frac{d \ln [1 - G(\underline{\theta})]}{d p_m(w)} = \frac{\partial \ln [1 - G(\underline{\theta})]}{\partial \ln p_m(w)} \frac{\partial \ln p_m(w)}{\partial p_m(w)} \Leftrightarrow$$

$$\Leftrightarrow \frac{1}{[1 - G(\underline{\theta})]} \left(-g(\underline{\theta}) \frac{\partial \underline{\theta}}{\partial p_m} \right) = \frac{\partial \ln [1 - G(\underline{\theta})]}{\partial \ln p_m(w)} * \frac{1}{p_m(w)} \Leftrightarrow$$

$$\Leftrightarrow \frac{d \ln [1 - G(\underline{\theta})]}{d \ln p_m(w)} = \frac{-g(\underline{\theta}) \dfrac{\partial \underline{\theta}}{\partial p_m} p_m(w)}{[1 - G(\underline{\theta})]} \Leftrightarrow -\frac{\partial \ln [1 - G(\underline{\theta})]}{\partial \ln p_m(w)} = \frac{g(\underline{\theta}) \dfrac{\partial \underline{\theta}}{\partial p_m} p_m(w)}{[1 - G(\underline{\theta})]}]$$

[note that in general: $\xi_x f(x) = \dfrac{\partial f(x)}{\partial x} \dfrac{x}{f(x)} = \dfrac{\partial \ln f(x)}{\partial \ln x}$] ■

Appendix B

Formulation and solution to the dynamic water pricing and investment model with a financial constraint

This Appendix describes the formulation and the solution to the dynamic water pricing and investment model with a financial constraint. We formulate the problem as an isoperimetric one by adding the following budget balancing constraint to the problem 4.28:

$$\int_{0}^{\infty} e^{-rt} \left\{ D\left(f\left(K_t, \phi_t\right), \phi_t\right) f\left(K_t, \phi_t\right) - C\left(f\left(K_t, \phi_t\right), \phi_t\right) - I_t - c\left(I_t\right) \right\} dt = 0 \tag{B.1}$$

We choose to adopt a global constraint for the time horizon to reflect a perfect capital market as in Brock and Dechert (1985). The resulting autonomous differential equation system is:

$$\dot{I} = \frac{(r+\delta)\left[1 + \frac{\partial c(I)}{\partial I}\right] - \left[1 + \frac{\lambda}{(1+\lambda)} f\left(K, \phi\right)\right] \frac{\partial BL(K,\phi)}{\partial K}}{\frac{\partial^2 c(I)}{\partial I^2}} \tag{B.2}$$

$$\dot{K} = I - \delta K \tag{B.3}$$

and the steady-state is characterized by:

$$\left\{ \begin{array}{c} \dot{K} = 0 \\ \dot{I} = 0 \end{array} \right. \Leftrightarrow \left\{ \begin{array}{c} I = \delta K \\ 1 + \frac{\partial c(I)}{\partial I} = \frac{\left[1 + \frac{\lambda}{(1+\lambda)} f(K,\phi)\right] \frac{\partial BL(K,\phi)}{\partial K}}{(r+\delta)} \end{array} \right. \tag{B.4}$$

The steady state equilibrium is a stable node if the following expression is greater than 1 or a saddle point if it is less than 1:

$$\frac{-\frac{\partial f(K,\phi)}{\partial K}\frac{\partial BL(K,\phi)}{\partial K}}{\left[1+\frac{\lambda}{(1+\lambda)}f\left(K,\phi\right)\right]\frac{\partial^2 BL(K,\phi)}{\partial K^2}}$$

Comparative statics derivatives are less informative for the isoperimetric problem, but the sign and magnitude of $\frac{d}{d\phi}\left[\frac{\partial BL(f(K,\phi),\phi)}{\partial K}\right]$ is still an important factor in determining whether optimal steady-state leves of capital and investment should rise or fall in a global warming context.

Appendix C

Residential water demand estimation studies

Authors	Year of publication	Where Published	Type of data	Periodicity	Econometric method	Number of observations	Study area	Functional form	Type of demand
Bartczak et al.	2009	WP - Warsaw Ecological Economics Center, Warsaw University	Panel data (aggregate)	Annual (2001-2005)	RE-GLS, corrected for autocorrelation; FGLS, Paris-Winsten with panel-corrected standard errors	195 (39 municipal districs*5 years)	Poland	Double logarithmic (loglinear or log-log)	Residential
Diakité et al.	2009	Journal of Development Economics	Panel data (aggregate)	Annual (1998-2002)	Discrete-Continuous Choice model, multinomial logit for the choice of block and 3SLS, FE, OLS, GLS	780 (156 local communities*5 years)	Côte d'Ivoire	Linear	Residential
Garcia-Valiñas et al.	2009	Paper presented at the 17th Annual Conference of EAERE (EAERE 2008)	Panel data (aggregate)	Annual (1998, 2001 and 2004)	FE	6911	France	Stone-Geary	Residential
Olmstead	2009	Journal of Business and Economic Statistics	Panel data (household data)	Daily (2 weeks in wet season and 2 weeks in arid season)	Discrete-Continuous choice model (maximum likelihood); Panel datechniques (random effects); IV ("IV model is a two-stage GLS random-effects model for panel data."); Monte Carlo study of estimators' properties	1342 (671 households * 2 seasons)	7 urban areas (Denver, Seattle, San Diego, Tampa, Phoenix, Tempe/Scottsdale [USA] and Las Virgenes [Canada]) served by 10 water utilities (USA and Canada)	Double logarithmic (loglinear or log-log)	Residential
Ruijs	2009	Environmental and Resource Economics (forthcoming)	Time series (aggregate)	Monthly (July 1997-December 2002)	OLS	64	Metropolitan region of São Paulo (Brazil)	Linear	Residential
Schleich	2009	Paper presented at the 17th Annual Conference of EAERE (EAERE 2008)	Cross-section (aggregate data)	Annual (2003)	OLS	592 water supply areas in Germany	Germany	Stone-Geary, linear and Log-linear (log-log)	Residential
Schleich and Hillenbrand	2009	Ecological Economics	Cross-section (aggregate)	Annual (2003)	OLS and IV; Hausman test performed (no endogeneity found)	592 water supply areas in Germany	Germany	Double logarithmic (loglinear or log-log) and semilogarithmic (log-lin and lin-log)	Residential
Arbués-Gracia et al.	2008	Paper presented at the 3rd AERNA Congress	Panel data (household data)	Quarterly (10 meter readings between 1996 and 1998)	2 SLS, RE	15070 (1507 sampled households, 10 quarters)	Zaragoza (Spain)	Semilogarihmic (log-lin)	Residential
Azomahou	2008	Cliometrica	Panel data (aggregate)	Biannual (1988-1993)	2 stage autoregressive spatial model: maximum likelihood methods used in the first stage; minimum distance estimator used in the second stage	1380 (12 semesters * 115 municipalities)	115 municipalities from the department Moselle (out of 730 municipalities in this department) in northeast France (France)	Spatial autoregressive model	Residential

Authors	Year of publication	Where Published	Type of data	Periodicity	Econometric method	Number of observations	Study area	Functional form	Type of demand
Basani et al.	2008	World Development	Cross-section (household data)	Monthly (-)	2-step Heckman procedure, including selection model (probit) for connection and OLS	428 connected households + 354 non-connected households	Cambodja	Double logarithmic (loglinear or log-log)	Residential
Bell and Griffin	2008	Water Resources Research	Panel data (aggregate)	Monthly (1999-2003)	FE	18468 from an original data set of 23100 (385 water providers * 60 months)	Texas (USA)	Log-nonlinear (differences in logs)	Municipal
Cheesman et al.	2008	Water Resources Research	Panel data (household data)	Monthly (2006)	Contingent behavior, 2-step Heckman procedure, including selection model (probit), RE-GLS, SUR	390 (130 households, 1 revealed preference plus 2 contingent behavior responses per household)	Buon Ma Thuot, Dak Lak Province (Vietnam)	Double logarithmic (loglinear or log-log)	Residential
Frondel and Messner	2008	Paper presented at the 16th Annual Conference of EAERE (EAERE 2008) in a poster session	Panel data (household data)	Annual (1998-2001)	Endogenous switching regression model, Pooled OLS	760 (140 households*4 years)	Leipzig (Germany)	Double logarithmic (loglinear or log-log)	Residential
Kenney et al.	2008	Journal of the American Water Resources Association	Panel data (household data)	Monthly (2000-2005)	FE-IV	approximately 680000 (from over 10000 accounts)	Aurora, Colorado (USA)	Double logarithmic (loglinear or log-log)	Residential
Miyawaki et al.	2008	WP - Center for International Research on the Japanese Economy	Panel data (household data)	Monthly (June 2006-May 2008)	Bayesian estimation (Markov chain Monte Carlo simulation; Gibbs sampling). Discrete/Continuous Choice Model + Panel data techniques (RE and Dynamic panel data techniques)	365 (cross-section); 229 (panel; 2 periods: June 2006 and June 2007)	Tokyo and Chiba prefectures (Japan)	Double logarithmic (loglinear or log-log)	Residential
Nataraj and Hanemann	2008	CUDARE WP - Department of Agricultural & Resource Economics, University of California, Berkeley	Panel data (household data)	Bimonthly (July-August, 1990-2000)	Regression Discontinuity Design	103044 (from 9486 single-family households)	Santa Cruz, California (USA)	Linear	Residential

Authors	Year of publication	Where Published	Type of data	Periodicity	Econometric method	Number of observations	Study area	Functional form	Type of demand
Nauges and Berg	2008	Environmental and Resource Economics	Cross-section (household data)	Monthly (2003)	Simultaneous equations, IV (2SLS); 2-step Heckman procedure, including selection model (probit) for connection; Tobit model, ML	1718	Gampaha, Kalutara and Galle, Southwest Sri Lanka (Sri Lanka)	Double logarithmic (loglinear or log-log)	Residential
Reynaud	2008	Paper presented at the 16th Annual Conference of EAERE (EAERE 2008)	Panel Data (Aggregate)	Every 3 years (1998, 2001 and 2004)	Pooled OLS, FE, RE	904 observations (338 local communities * 3 years - removal of missing observations)	Midi-Pyrénées region in Southwest of France (France)	Double logarithmic (loglinear or log-log)	Residential
Ruijs et al.	2008	Ecological Economics	Time series (aggregate)	Monthly (July 1997-December 2002)	OLS (for the MP model); 2SLS (for the AP model)	64	Metropolitan region of São Paulo (Brazil)	Linear	Residential
Statzu and Strazzera	2008	Temi Economici della Sardegna - Quaderni di Lavoro Crenos 08/03	Panel data (aggregate)	Yearly (2000-2005)	FE, RE-GLS, Hausman-Taylor, Amemya-Mcurdy, Fixed-Effects Vector Decomposition	1440 (6 years*240 towns)	Sardinia (Italy)	Double logarithmic (loglinear or log-log)	Residential
Strong and Smith	2008	WP - NBER	Cross-section (aggregate)	Monthly (2005)	Nonlinear least squares; Discrete/Continuous Choice models	516 (43 utilities*12 months)	Phoenix, Arizona (USA)	Nonlinear	Residential
Xayavong et al.	2008	WP - The University of Western Australia, School of Agricultural and Resource Economics	Panel data (household data)	Annual (1995-2005)	ML, Tobit model to estimate the proportion of households per block	2390 (234 suburbs * 11 years)	Perth, Western Australia (Australia)	Linear	Residential
Babel et al.	2007	Water Resources Management	Time Series (Aggregate)	Annual (1988-2001)	OLS	14 (Annual observations 1988-2001)	Kathmandu Valley, Nepal	Linear, Semilogarithmic (log-lin); Double logarithmic (loglinear or log-log)	Residential
Dahan and Nisan	2007	Water Resources Research	Cross-section (household data)	Annual (2003)	OLS, 2 SLS, Discrete/Continuous Choice model (ML)	51167	Jerusalem (Israel)	Linear and double logarithmic (loglinear or log-log)	Residential
Fullerton et al.	2007	Atlantic Economic Journal	Time-series (Aggregate)	Monthly (January 1997-December 2003)	Multiple-input transfer function technique (LTF method: extension of the transfer ARIMA approach)	84	Tijuana (Mexico)	Linear	Municipal
Grafton and Kompas	2007	Australian Journal of Agricultural and Resource Economics	Time Series (Aggregate)	Daily (28/10/2001-30/09/2005)	OLS (with AR(1) process, White Heteroskedasticity Consistent Standard Errors & Covariance)	1142 (1434 after adjustments)	Sydney (Australia)	Double logarithmic (loglinear or log-log)	Residential
Grafton and Ward	2007	Australian Journal of Agricultural and Resource Economics	Time-series (Aggregate)	Daily (01/01/1994-30/09/2005)	OLS	4291	Sydney (Australia)	Double logarithmic (loglinear or log-log)	Residential

Authors	Year of publication	Where Published	Type of data	Periodicity	Econometric method	Number of observations	Study area	Functional form	Type of demand
Mansur and Olmstead	2007	WP - National Bureau of Economic Research	Panel data (household data)	Daily (2 two-week periods: summer, winter)	2SLS, ML, Tobit (outdoor demand), FE, RE	2164 (2 periods*1082 households)	11 urban areas (USA and Canada)	Semilogarithmic (log-lin)	Residential (only detached single family homes)
Martínez-Espiñeira	2007	Journal of Applied Economics	Time-series (Aggregate)	Monthly (1991-1999)	Co-integration, Error-correction model	108 (12 months * 9 years)	Seville (Spain)	Linear	Residential
Martins and Fortunato	2007	Water Policy	Panel data (aggregate)	Monthly (January 1998-December 2003)	IV, RE (with GLS and correction for a 1st order autoregressive disturbance process)	360 (5 local communities and 72 months)	Centre region (Portugal)	Linear	Residential
Musolesi and Nosvelli	2007	Applied Economics Letters	Panel data (aggregate)	Annual (1998-2001)	System GMM	408 (102 municipalities*4 years)	Cremona Province (Italy)	Double logarithmic (loglinear or log-log)	Residential
Nauges and Strand	2007	Resource and Energy Economics	Cross-section (household data)	Surveys performed between 1995-1997	two-step procedure: 1st step - multinomial logit model to select the water source; 2nd step OLS (with Lee correction method) on log-log functional form. Bootstrapping	1379 (553 non-tap households in El Salvador and 826 non-tap households in Honduras)	3 cities (El Salvador) and in marginal barrios in Tegucigalpa (Honduras)	Double logarithmic (loglinear or log-log) (2nd step)	Residential

Authors	Year of publication	Where Published	Type of data	Periodicity	Econometric method	Number of observations	Study area	Functional form	Type of demand
Olmstead et al.	2007	Journal of Environmental Economics and Management	Panel data (household data)	Daily (2 weeks in wet season and 2 weeks in arid season)	Discrete-Continuous choice model (DCC model) involving Maximum Likelihood estimation; A panel random-effects (GLS) model is estimated for uniform price observations only. Bootstrap used on elasticities	N=25666 (1082 households in 11 urban areas in the United States and Canada, served by 16 public water utilities; 4 weeks of daily measurements).	Denver, Eugene, Seattle, San Diego, Tampa, Phoenix, Tempe/Scottsdale, Waterloo/Cambridge (Ontario), Walnut Valley, Las Virgenes, and Lompoc (USA and Canada)	Double logarithmic (loglinear or log-log)	Residential
Yoo	2007	Applied Economics Letters	Cross-section (household data)	Monthly (2002)	Sample selection model (to detect and correct for sample selection bias)	804 households	Korean metropolitan cities (Seoul, Pusan, Daegu, Incheon, Kwangju, Daejeon and Ulsan) (South Korea)	Double logarithmic (loglinear or log-log)	Residential
Arbués and Villanua	2006	Urban Studies	Panel data (household data)	Quarterly (10 meter readings between 1996 and 1998)	Dynamic panel data techniques (two-step Arellano-Bond + Between estimator in another step to estimate the parameters of time-invariant variables)	15960 (10 meter readings in the period 1996-1998 * 1596 users)	Zaragoza (Spain)	Linear, double logarithmic (loglinear or log-log) and semilogarithmic (linear functional form chosen as best based on the Schwarz BIC criterion)	Residential
Fullerton et al.	2006	Atlantic Economic Journal	Time-series (Aggregate)	Monthly (2000-2004)	Linear Transfer Function ARIMA	60	Ciudad Juárez (Mexico)	Linear	Municipal
Garcia-Valiñas	2006	Applied Economics	Panel data (household and firm data)	Quarterly (1991(4)-2000 (3))	GMM	493992 (1372 households*36 quarters) and 9216 (256 firms*36 quarters)	Seville, Andalusia (Spain)	Linear	Residential and commercial/industrial
Gaudin	2006	Applied Economics	Cross-Section (Aggregate)	Annual	OLS (Hausman test performed with IV/2SLS on price endogeneity "log values of the total charges for 3750-gallon and 7500-gallon monthly bills are used in addition to the other exogenous variables to instrument price" (no evidence of systematic bias found)	383 water utilities	USA	Double logarithmic (loglinear or log-log)	Residential

Authors	Year of publication	Where Published	Type of data	Periodicity	Econometric method	Number of observations	Study area	Functional form	Type of demand
Hoffmann et al.	2006	Australian Journal of Agricultural and Resource Economics	Time series (aggregate)	Quarterly (September 1998 June 2003)	OLS	20 quarters	Brisbane (Australia)	Linear and double logarithmic (loglinear or log-log)	Residential
Jansen and Schulz	2006	South African Journal of Economics	Panel data (household data)	Monthly (July 1998-June 2003)	2SLS; Panel Corrected Standard Errors Model (PCSE); RE AR(1); FE AR(1); GLS; Pooled OLS	up to 16500 (unbalanced panel of 275 households and 60 months)	Cape Town (South Africa)	Double logarithmic (loglinear or log-log)	Residential
Kostas and Chrysostomos	2006	South-Eastern Europe Journal of Economics	Time series (aggregate)	Annual (1981-1999)	OLS	20	Athens (Greece)	Stone-Geary	Residential
Larson et al.	2006	Journal of Development Studies	Cross-section (household data)	Monthly (2000)	2-step Heckman procedure, including selection model (logit) for connection, ML	547	Fianarantsoa (Madagascar)	Linear	Residential
Mazzanti and Montini	2006	Applied Economics Letters	Panel data (aggregate)	Annual (1998-2001)	FE, chosen after Hausman test	500 (125 municipalities*4 years)	Emilia-Romagna (Italy)	Double logarithmic (loglinear or log-log)	Residential
Carter and Milon	2005	Land Economics	Panel data (household data)	Monthly (1997-1999)	Probit for the decision to acquire price knowledge, OLS; 2-stage Simultaneous equations techniques with endogenous switching	24695 from a potential of 26712 (742 households*36 months)	Florida (USA)	Double logarithmic (loglinear or log-log)	Residential
Dalmas and Reynaud	2005	Chapter in the book Koundouri (ed.) "Econometrics Informing Natural Resources Management: Selected Empirical Analyses"	Panel data (aggregate)	Annual (1999-2001)	RE-GLS, OLS	213 (3 years * 71 municipalities)	Slovak Republic	Linear, double logarithmic (loglinear or log-log) and Stone-Geary	Residential
Garcia-Valiñas	2005	Environmental and Resource Economics	Panel data (household and firm data)	Quarterly (1991(4)-2000 (3))	GMM	493992 (1372 households*36 quarters) and 9216 (256 firms*36 quarters)	Seville, Andalusia (Spain)	Linear	Residential and industrial/commercial
Garcia-Valiñas	2005	Revista de Economía Pública	Panel data (household and firm data)	Quarterly (1994-2000)	GMM, FE, Hausman tests, Sargan tests for instrument validity	41175 (1525 households*27 quarters) and 2160 (80 firms*27 quarters)	Elche, Alicante (Spain)	Linear	Residential and industrial/commercial

Authors	Year of publication	Where Published	Type of data	Periodicity	Econometric method	Number of observations	Study area	Functional form	Type of demand
Hoffmann et al.	2006	Australian Journal of Agricultural and Resource Economics	Time series (aggregate)	Quarterly (September 1998 June 2003)	OLS	20 quarters	Brisbane (Australia)	Linear and double logarithmic (loglinear or log-log)	Residential
Jansen and Schulz	2006	South African Journal of Economics	Panel data (household data)	Monthly (July 1998-June 2003)	2SLS; Panel Corrected Standard Errors Model (PCSE); RE AR(1); FE AR(1); GLS; Pooled OLS	up to 16500 (unbalanced panel of 275 households and 60 months)	Cape Town (South Africa)	Double logarithmic (loglinear or log-log)	Residential
Kostas and Chrysostomos	2006	South-Eastern Europe Journal of Economics	Time series (aggregate)	Annual (1981-1999)	OLS	20	Athens (Greece)	Stone-Geary	Residential
Larson et al.	2006	Journal of Development Studies	Cross-section (household data)	Monthly (2000)	2-step Heckman procedure, including selection model (logit) for connection, ML	547	Fianarantsoa (Madagascar)	Linear	Residential
Mazzanti and Montini	2006	Applied Economics Letters	Panel data (aggregate)	Annual (1998-2001)	FE, chosen after Hausman test	500 (125 municipalities*4 years)	Emilia-Romagna (Italy)	Double logarithmic (loglinear or log-log)	Residential
Carter and Milon	2005	Land Economics	Panel data (household data)	Monthly (1997-1999)	Probit for the decision to acquire price knowledge, OLS; 2-stage Simultaneous equations techniques with endogenous switching	24695 from a potential of 26712 (742 households*36 months)	Florida (USA)	Double logarithmic (loglinear or log-log)	Residential
Dalmas and Reynaud	2005	Chapter in the book Koundouri (ed.) "Econometrics Informing Natural Resources Management: Selected Empirical Analyses"	Panel data (aggregate)	Annual (1999-2001)	RE-GLS, OLS	213 (3 years * 71 municipalities)	Slovak Republic	Linear, double logarithmic (loglinear or log-log) and Stone-Geary	Residential
Garcia-Valiñas	2005	Environmental and Resource Economics	Panel data (household and firm data)	Quarterly (1991(4)-2000 (3))	GMM	493992 (1372 households*36 quarters) and 9216 (256 firms*36 quarters)	Seville, Andalusia (Spain)	Linear	Residential and industrial/commercial
Garcia-Valiñas	2005	Revista de Economía Pública	Panel data (household and firm data)	Quarterly (1994-2000)	GMM, FE, Hausman tests, Sargan tests for instrument validity	41175 (1525 households*27 quarters) and 2160 (80 firms*27 quarters)	Elche, Alicante (Spain)	Linear	Residential and industrial/commercial

Authors	Year of publication	Where Published	Type of data	Periodicity	Econometric method	Number of observations	Study area	Functional form	Type of demand
García-Valiñas	2005	Chapter in the book Koundouri (ed.) "Econometrics Informing Natural Resources Management: Selected Empirical Analyses"	Panel data (household and firm data)	Bimonthly (1994-2000)	System GMM	Residential: 65340 (1089 households*60 periods); Commercial/Industrial: 28620 (477 firms*60 periods)	Gijón, Asturias (Spain)	Linear	Residential and Commercial / Industrial
Gaudin	2005	Water Supply	Cross-section (aggregate)	Annual (1995/96)	OLS (Hausman test performed with IV/2SLS on price endogeneity "log values of the total charges for 3750-gallon and 7500-gallon monthly bills are used in addition to the other exogenous variables to instrument price" (no evidence of systematic bias found)	383 water utilities	USA	Double logarithmic (loglinear or log-log)	Residential
Hanemann and Nauges	2005	CUDARE WP - Department of Agricultural & Resource Economics, University of California, Berkeley	Panel data (household data)	Bimonthly (1988-1992)	Pooled OLS, FE, RE	3884002 (from na "unbalanced panel gathering 177,834 single-family residential customers")	Los Angeles, California (USA)	Double logarithmic (loglinear or log-log)	Residential
Martins and Fortunato	2005	Tecnologia da Agua	Cross-section (aggregate)	Annual (divided by 12 to get monthly) (2002)	2SLS, Maximum likelihood	278 municipalities	Portugal excluding Azores and Madeira	Linear	Residential
Reynaud and Thomas	2005	Revue Economique	Panel Data (aggregate)	Annual (1990-1994)	Selection model: Probit (for the choice of water utility type); RE (with BMS instruments for the direct management equation)	545 (109 municipalities*5 years)	Gironde (France)	Double logarithmic (loglinear or log-log)	Residential

Authors	Year of publication	Where Published	Type of data	Periodicity	Econometric method	Number of observations	Study area	Functional form	Type of demand
Reynaud et al.	2005	Water Resources Research	Cross-section (aggregate)	Annual (1999)	Multinomial logit (for the pricing structure choice)	899 local communities	Canada	Double logarithmic (loglinear or log-log)	Residential
Strand and Walker	2005	Environment and Development Economics	Cross-section (household data)	Monthly (the month before the survey) (1995 to 1998 according to city)	2SLS	3700 tap and nontap water users	17 cities in Central America and Venezuela: Tegucigalpa, San Pedro Sula, Santa Rosa de Copán, and Comayagua (Honduras); Managua (Nicaragua); Santa Ana, Sonsonate and San Miguel (El Salvador); Barquisimeto and Merida (Venezuela); Guatemala City, Villa Nueva, Chinautla, and Mixco (Guatemala); and Panama City and Colón (Panama)	Linear and double logarithmic	Residential
Arbués et al.	2004	Water Resources Research	Panel data (household data)	Quarterly (10 meter readings between 1996 and 1998)	GMM (Arellano-Bond estimator) and RE	15960 (1596 households* 10 quarters)	Zaragoza (Spain)	Semilogarithmic (log-lin)	Residential
Fullerton and Elías	2004	Water Resources Research	Time-series (Aggregate)	Monthly (1994-2002)	Linear Transfer Function ARIMA	108	El Paso, Texas (USA)	Linear	Municipal
Garcia and Reynaud	2004	Resource and Energy Economics	Panel data (Aggregate)	Annual	GMM	50 water utilities studied annualy 1995-98 (200 observations)	Bordeaux (France)	Double logarithmic (loglinear or log-log)	Residential and industrial aggregated

Authors	Year of publication	Where Published	Type of data	Periodicity	Econometric method	Number of observations	Study area	Functional form	Type of demand
Martínez-Espiñeira and Nauges	2004	Applied Economics	Time-Series (Aggregate)	Monthly (1991-1999)	IV, Time-series techniques (correction for AR(p) process in residuals)	108	Seville (Spain)	Stone-Geary	Residential
Mylopoulos et al.	2004	Water International	Panel data (household data)	Bimonthly (January 1994-April 2000)	FE, RE	27564 observations (1356 households in 17 municipalities and 19 bimonthy time-series observations)	Thessaloniki (Greece)	Double logarithmic (loglinear or log-log)	Residential
Taylor et al.	2004	Land Economics	Panel data (aggregate)	Monthly (1984-1985)	OLS, 2SLS	816 (34 utilities*24 months)	Colorado (USA)	Linear and double logarithmic (loglinear or log-log)	Residential
Ayadi et al.	2003	Paper presented at the 10th Annual Economic Research Forum	Panel data (aggregate)	Quarterly (1980-1996)	SURE, GLS, 3SLS, FE	408 (6 regions * 68 quarters)	Tunisia	Double logarithmic (loglinear or log-log)	Residential
Dalhuisen et al.	2003	Land Economics	Water demand studies	Studies conducted between 1963 and 2001	Meta-analysis	296 (price-elasticity); 162 (income-elasticity) from 64 studies	From around the world (several articles with different study areas)	Linear, Box-Cox	Residential
Fullerton and Nava	2003	Water Resources Research	Time-series (Aggregate)	Monthly (1998-2000)	Linear Transfer Function ARIMA	36	Chihuahua City (Mexico)	Linear	Municipal

Authors	Year of publication	Where Published	Type of data	Periodicity	Econometric method	Number of observations	Study area	Functional form	Type of demand
Garcia and Thomas	2003	Environmental and Resource Economics	Panel data (aggregate)	Annual (1998-2005)	FE	192 (48 water utilities * 4 years)	Bordeaux (France)	Linear	Municipal
Krause et al.	2003	Journal of Regulatory Economics	Panel data (Individual experimental data)	-	FGLS	114	Albuquerque, New Mexico (USA)	Linear	Residential
Martínez-Espiñeira	2003	Environmental and Resource Economics	Panel data (Aggregate)	Monthly (transformed from quarterly billing data: January 1995-June 1999)	Discrete-Continuous choice model: 2 stages: 1st stage: Discrete choice estimation of the proportion of users ending up in each block (multinomial logit); 2nd stage: continuous estimation of the unconditional demand function (panel data estimation - GLS)	Multinomial logit (1st stage): 183 observations in an unbalanced panel (4 cross-sectional groups * 54 months = 216 [if the panel was balanced and complete]). 2nd stage: 120 obsrvations in a balanced panel (4 communities * 30 months [March 1996-September 1998])	3 towns in the northwest of Spain	Linear	Residential
Nauges and Thomas	2003	Environmental and Resource Economics	Panel data (Aggregate)	Annual (1988-1993)	Dynamic Panel Data Model Techniques, GMM	696 (116 communities*6 years)	France	Double logarithmic (loglinear or log-log)	Residential
Piper	2003	Water Resources Research	Cross-section (aggregate)	Annual (1996)	3SLS	309	USA	Semilogarithmic (log-lin)	Residential
Acharya and Barbier	2002	American Journal of Agricultural Economics	Cross-section (Household data)	1995-1996	Contingent behavior, RE-GLS, SUR-FGLS	556 (purchased water); 590 (collected water) (combination of revealed preferences with contingent behavior responses from 110 households)	Hadejia–Jama'are floodplain (Nigeria)	Linear	Residential
Agthe and Billings	2002	Journal of Water Resources Planning and Management	Cross-section (aggregate data from apartment complexes)	Intra-annual (1988; 4 winter months, 4 summer months)	OLS	308	Tucson, Arizona (USA)	Linear	Residential
Hajispyrou et al.	2002	Environment and Development Economics	Cross-section (household data)	Annual (1996-1997)	OLS, IV, ML	2700	Cyprus	Quadratic logarithmic - Quadratic Almost Ideal Demand System (QUAIDS)	Residential
Ipe and Bhagwat	2002	Applied Economics	Time-series (aggregate)	Annual (1970-1997)	OLS	28	Chicago Metropolitan Area (USA)	Linear	Municipal

Authors	Year of publication	Where Published	Type of data	Periodicity	Econometric method	Number of observations	Study area	Functional form	Type of demand
Martínez-Espiñeira	2002	Environmental and Resource Economics	Panel data (aggregate)	Monthly (standardized from bimonthly or quarterly billing data; 1993-1999)	FE, 2nd step to recover coefficients of the time-invariant regressors; number of users in the municipality used to weight the observations	From 991 (summer regression) to 2792 observations (122 towns * 22,88 months was the average lenght of the time series in the unbalanced panel)	Northwest Spain	Linear	Residential
Nauges and Blundell	2002	WP - LERNA-INRA	Cross-section (household data)	Annual (1997)	Nonparametric series estimator (compared with OLS, 2SLS and ML)	1686 households from 2700 sampled households (households who face a 3-block tariff were chosen)	Cyprus	No functional form assumed in nonparametric estimation (double logarithmic used for the alternative parametric estimation techniques)	Residential
Pashardes and Hajispyrou	2002	WP - Department of Economics, University of Cyprus	Cross-section (household data)	Annual (1996/97)	Discrete-Continuous Choice model, nonlinear FIML	2468	Cyprus	Quadratic logarithmic - Quadratic Almost Ideal Demand System (QUAIDS)	Residential
Gaudin et al.	2001	Land Economics	Panel data (Aggregate)	Monthly (1981-1985)	OLS; RE; nonlinear GLS	9340 from a potential of 13260 (221 communities * 60 months)	Texas (USA)	Stone-Geary; Generalized Cobb-Douglas	Residential
Gunatilake et al.	2001	International Journal of Water Resources Development	Panel data (Household data)	Monthly (1994-1999)	GLS (Prais-Winsten transformation)	1385 from a potential of 2880 (40 households * 72 months)	Kandy municipality (Sri Lanka)	Double logarithmic (loglinear or log-log)	Residential
Higgs and Worthington	2001	Public Works Management & Policy	Cross-section (household data)	Annual (-)	OLS and IV; Logit model for the choice between two pricing methods: flat rate or volumetric	350	Brisbane (Australia)	Linear	Residential
Nauges and Reynaud	2001	Revue Economique	Panel data (Aggregate)	Annual (1989-1994)	FE	436 (109 municipalities/associations of municipalities within the Gironde department for the period 1990-1994) and 464 (116 municipalities within the Moselle department for the period 1989-1993)	2 departements: Moselle and Gironde (France)	Double logarithmic (loglinear or log-log)	Residential

Authors	Year of publication	Where Published	Type of data	Periodicity	Econometric method	Number of observations	Study area	Functional form	Type of demand
Nauges and Thomas	2000	Land Economics	Panel data (aggregate)	Annual (1988-1993)	FE	696 (116 local communities for the period 1988-1993)	East of France (France)	Double logarithmic (loglinear or log-log)	Total
Renwick and Green	2000	Journal of Environmental Economics and Management	Panel data (aggregate)	Monthly (1989-1996)	GLS, IV(2SLS) corrected for heteroskedasticity and an AR(12) process	768 (8 water agencies*96 months)	California (USA)	Double logarithmic (loglinear or log-log)	Residential
Rietveld et al.	2000	Bulletin of Indonesian Economic Studies	Cross-section (household data)	Annual (1994)	Discrete-Continuous Choice Model; Maximum Likelihood	475 households	Salatiga city, Java (Indonesia)	Double logarithmic (loglinear or log-log)	Residential
Corral et al.	1999	CUDARE WP - Department of Agricultural & Resource Economics, University of California, Berkeley	Panel data (aggregate)	Monthly (January 1982-October 1992)	Discrete-Continuous Choice model, multinomial logit for the choice of block and 2SLS	390 (3 water districts*130 months)	3 water districts in the San Francisco Bay Area (USA)	Linear	Residential
Dzisiak	1999	M. Sc. - University of Manitoba, Faculty of Graduate Studies, Department of Agricultural Economics	Panel data (aggregate)	Quarterly (1986, 89, 91 and 92)	OLS	206 (from an unbalanced panel of 25 communities and 16 quarters)	Alberta, Manitoba and Saskatchewan provinces (Canada)	Linear; double logarithmic (loglinear or log-log)	Residential
Höglund	1999	Water Resources Research	Panel data (Aggregate)	Annual (1980-1992)	Panel data techniques (static and dynamic), OLS, GLS, 2SLS	282 communities (out of 286) studied annualy 1980-1992 (3190 observations because of missing data [282*13 = 3666] for static models and 1485 observations for dynamic models [135*11])	Sweden	Linear	Residential
Merrified and Collinge	1999	Public Works Management & Policy	Cross-section (aggregate)	Annual (1991)	OLS	30	San Antonio, Texas (USA)	Linear, double logarithmic (loglinear or log-log) and Box-Cox	Residential
Pint	1999	Land Economics	Panel data (household data)	Bimonthly (1982-1992)	Panel Data Techniques (Fixed-effects model), Maximum Likelihood, Discrete/continuous choice model - choice of block (Probit)	599 single-family households, studied bimonthly 1/1982-7/1992 (37737 observations [599*63])	Alameda County Water District (ACWD) - Fremont, Newark and Union City, California (USA)	Linear	Residential
Renzetti	1999	Canadian Journal of Economics	Cross-section (aggregate)	Annual (1991)	OLS	77	Ontario (Canada)	Double logarithmic (loglinear or log-log)	Residential and nonresidential

Authors	Year of publication	Where Published	Type of data	Periodicity	Econometric method	Number of observations	Study area	Functional form	Type of demand
Billings and Agthe	1998	Journal of Water Resources Planning and Management	Time Series (Aggregate)	Monthly (1974-1988)	IV, state-space modelling	84	Tucson, Arizona (USA)	Linear	Residential
David and Inocencio	1998	WP - Economy and Environment Program for Southeast Asia	Cross-section (household data)	Monthly (1995)	OLS, 2SLS	506	Metro Manila (Philippines)	Linear and double logarithmic (loglinear or log-log)	Residential (connected and non-connected)
Largo et al.	1998	Philippine Institute for Development Studies Discussion Paper	Cross-section (household data)	Monthly (-)	2SLS	466	Metro Cebu (Philippines)	Linear and double logarithmic (loglinear or log-log)	Residential (connected and non-connected)
Mattos	1998	Pesquisa e Planejamento Econômico	Time Series (Aggregate)	Monthly (1993-1996)	OLS, 2SLS	48	Piracicaba, São Paulo (Brazil)	Linear	Residential
Renwick and Archibald	1998	Land Economics	Panel data (household data)	Monthly (1985-1990)	IV, 2SLS, Probit and ML (for the technology adoption equations)	8568 (119 households*72 months)	Santa Barbara, California (USA)	Linear	Residential
Agthe and Billings	1997	Journal of Water Supply Research and Technology - AQUA	Cross-section (household data)	Monthly (January 1977-December 1981 and January 1986-December 1988)	IV	106560 (1110 households * 96 months)	Tucson, Arizona (USA)	Semilogarithmic (log-lin)	Residential
Dandy et al.	1997	Land Economics	Panel data (household data)	Intra-annual (6 months periods) (1978/79-1991/92)	OLS	2710 (average period for the households = 8 1/2 years; 320 sampled households)	Adelaide, South Australia (Australia)	Linear	Residential
Espey et al.	1997	Water Resources Research	Water demand studies.	Studies published between 1967 and 1993.	Meta-Analysis (OLS)	124 estimations from 24 journal articles	USA	Linear, Semilogarithmic and Box-Cox	Residential
Malla and Gopalakrishnan	1997	International Journal of Water Resources Development	Panel data (data on multi-unit residences)	Monthly (August 1991-December 1994)	OLS and GLS	450 (15 multi-dwelling residential units * 30months)	Honolulu, Hawaii (USA)	Linear	Residential

Authors	Year of publication	Where Published	Type of data	Periodicity	Econometric method	Number of observations	Study area	Functional form	Type of demand
Saleth and Dinar	1997	Technical Paper - World Bank	Cross-section (household data)	Annual (1991-1992)	OLS	858	Hyderabad City, Andhra Pradesh (India)	Double logarithmic (loglinear or log-log)	Residential
Barkatullah	1996	WP - University of Sydney, Department of Economics	Panel data (household data)	Quarterly (1990-1994)	OLS, IV, ML and correction for AR(1) autocorrelation	17040 (1065 households*16 quarters	Sydney Metropolitan and Wollongong areas, New South Wales (Australia)	Double logarithmic (loglinear or log-log)	Residential
Dziegielewski	1996	Chapter in the book Hall (ed.) "Marginal Cost Rate Design and Wholesale Water Markets"	Water demand studies	-	Meta-analysis (OLS)	160 estimations from 38 studies	USA	Linear	Residential
Hansen	1996	Land Economics	Time-series (Aggregate)	Annual (1981-1990)	OLS (adjusted Durbin-Watson and Durbin tests showed no serial correlation)	30 (3 types of dwellings * 3 years)	Copenhagen (Denmark)	Linear, semilogarithmic (log-lin)	Residential
Andrade et al.	1995	Pesquisa e Planejamento Econômico	Cross-section (household data)	Monthly (March, 1986)	2SLS	5417	Paraná (Brazil)	Linear	Residential
Hewitt and Hanemann	1995	Land Economics	Panel data (Household data)	Monthly (Summer months, June-August, 1981-1985)	OLS, IV, 2SLS, Discrete/Continuous choice model - choice of block (Probit)	1703	Denton, Texas (USA)	Double logarithmic (loglinear or log-log)	Residential

Authors	Year of publication	Where Published	Type of data	Periodicity	Econometric method	Number of observations	Study area	Functional form	Type of demand
Bachrach and Vaughan	1994	WP - Inter-American Development Bank, Productive Sectors and Environment Subdepartment, Environment Protection Division	Cross-section (household data)	Annual (1987)	OLS, IV	685	34 rural localities in Argentina	Linear	Residential
Crane	1994	World Development	Cross-section (Household data)	Monthly (1991)	OLS	291	Jakarta (Indonesia)	Double logarithmic (loglinear or log-log)	Residential (water vendors and public taps [hydrants])
Walters and Young	1994	Colorado Water Resources Research Institute Completion Report	Panel data (aggregate)	Annual (1984-1985)	OLS	66 (33 utilities*2 years)	Colorado (USA)	Linear and semilogarithmic (log-lin)	Residential
Boistard	1993	Revue des Sciences de l'Eau (Journal of Water Science)	Panel data (aggregate)	Annual (1975, 1980, 1985, 1990)	OLS	8 classes aggregated from 1336 water utilities used in cross-section regressions in separate years (1975-1980). 2 groups aggregated from a panel of 500 utilities (1975-1990) used to calculated arc-elasticities	France	Linear and double logarithmic (loglinear or log-log)	Residential
Nieswiadomy and Cobb	1993	Contemporary Policy Issues	Cross-section (Aggregate)	Monthly (1984)	OLS, Logit model for tariff selection	229	USA	Double logarithmic (loglinear or log-log)	Residential
Point	1993	Revue Economique	Cross-section (aggregate)	Annual (1975)	OLS	62	Gironde (France)	Semilogarithmic (log-lin)	Municipal
Lyman	1992	Water Resources Research	Panel data (household data)	Bimonthly (1893-1987)	OLS	656 (30 households * 30 periods of two months each - lagging - errors in observations)	Moscow, Idaho (USA)	Double logarithmic (loglinear or log-log)	Residential
Martin and Wilder	1992	Public Finance Quarterly	Panel data (household data)	Monthly (July 1980-June 1981)	OLS, IV (2SLS)	About 83000 observations from approximately 19000 accounts (after deleting observations with missing values)	Columbia, South Carolina (USA)	Double logarithmic (loglinear or log-log)	Residential
Nieswiadomy	1992	Water Resources Research	Cross-section (Aggregate)	Monthly (1984)	OLS, IV, 2SLS (Hausman test did not reject endogeneity of MP and conservation and educational programs)	430	Different regressions for North Central, Northeast, South and West (USA)	Double logarithmic (loglinear or log-log) (after Box-Cox test)	Residential

Authors	Year of publication	Where Published	Type of data	Periodicity	Econometric method	Number of observations	Study area	Functional form	Type of demand
Renzetti	1992	Journal of Environmental Economics and Management	Time-Series	Quaterly (1975-1986)	IV (2SLS)	33 (industrial); ? (residential)	Vancouver (Canada)	Translog	Residential and industrial
Stevens et al.	1992	Water Resources Bulletin	Cross-section (Aggregate)	Annual (1985)	OLS, IV(2SLS)	85 communities	Massachussets (USA)	Linear	Residential
Woo	1992	Water Resources Research	Time-series (aggregate)	Monthly (1973-1984)	Box-Cox estimator, considering AR(1) error. Hausman test does not reject AP exogeneity	144	Hong Kong (China; UK at the time of study)	Box-Cox	Municipal
Griffin and Chang	1991	Western Journal of Agricultural Economics	Panel data (aggregate)	Monthly (1981-1985)	Pooled OLS	1105 (221 communities*5 years)	Texas (USA)	Linear, double logarithmic (loglinear or log-log), generalized Cobb-Douglas, translog, aumented Fourier	Residential and commercial
Nieswiadomy and Molina	1991	Land Economics	Panel data (Household data)	Monthly (1976-1985)	OLS, IV (2SLS) (Hausman test performed to demonstrate endogeneity)	5454 observations (101 households, studied monthly for 54 periods, the summer months: May to October, 1976-1980 [DBT], June to September 1981-1983, May-October 1984-1985 [IBT])	Denton, Texas (USA)	Double logarithmic (loglinear or log-log)	Residential
Rizaiza	1991	Water Resources Research	Cross-section (household data)	Annual (1985)	OLS	400	Jeddah, Makkah, Madina and Taif, Western Region (Saudi Arabia)	Double logarithmic (loglinear or log-log)	Residential
Schneider and Whitlatch	1991	Journal of Water Resources Planning and Management	Panel data (aggregate)	Annual (1959-1977)	Panel data techniques (GLS with and without partial adjustment, with and without time series and cross section dummy variables)	108-234 (6-13 communities * 18 years)	City of Columbus, Ohio (USA)	Linear	Residential, commercial, industrial, government, school and total.

Authors	Year of publication	Where Published	Type of data	Periodicity	Econometric method	Number of observations	Study area	Functional form	Type of demand
Billings	1990	Journal of Water Resources Planning and Management	Time-series (aggregate)	Monthly (January 1974-December 1980)	OLS	84	Tucson, Arizona (USA)	Linear and double logarithmic (loglinear or log-log); Dynamic Koyck	Residential
Griffin and Chang	1990	Water Resources Research	Panel data (Aggregate)	Monthly (January 1983-December 1985)	Pooled OLS	1031 observations from a potential of 1080 (30 communities * 36 months)	Texas (USA)	Linear	Residential and commercial
Miaou	1990	Water Resources Research	Time-series	Annual (1961-1980) from Cochran and Cotton, 1985 and Annual (1946-1971), from Young, 1973	Stepwise regression and ARIMA model for error	20 (Cochran and Cotton, 1985) and 26 (Young, 1973	Tucson, Arizona and Oklahoma City and Tulsa, Oklahoma (USA)	Linear and double logarithmic (loglinear or log-log)	Municipal
Mu et al.	1990	Water Resources Research	Cross-section (household data)	Daily	Discrete choice model for the type of water access; OLS for the demand equation	69	Ukunda, Mombasa (Kenya)	Linear, double logarithmic (loglinear or log-log) and semiligarithmic (log-lin and lin-log)	Residential (non-tap)
Billings and Day	1989	Journal of the American Water Works Association	Panel data (aggregate)	Monthly (1974-1980)	OLS	984 (from 11 water districts)	Tucson, Arizona (USA)	Linear	Residential
Moncur	1989	Water Resources Bulletin	Time-series (aggregate)	Monthly (1975-86)	ARIMA	95	Honolulu, Hawaii (USA)	Linear	Municipal
Nieswiadomy and Molina	1989	Land Economics	Panel data (Household data)	Monthly (summer months: May-October 1976-1980, June-September 1981-1983, May-October 1984-1985)	OLS, IV, 2SLS (Hausman test performed to demonstrate endogeneity)	5454 observations (101 households, studied monthly for 54 periods, the summer months: May to October, 1976-1980 [DBT], June to September 1981-1983, May-October 1984-1985 [IBT])	Denton, Texas (USA)	Linear	Residential

Authors	Year of publication	Where Published	Type of data	Periodicity	Econometric method	Number of observations	Study area	Functional form	Type of demand
Weber	1989	Water Resources Bulletin	Panel data (aggregate)	Monthly (January 1981-December 1987)	OLS	1008 (12 districts*84 months)	Oakland, California (USA)	Linear	Residential
Wilson	1989	Water Resources Research	Cross-section (Aggregate)	Annual (1964-1965)	OLS	12	12 suburban areas near Oakland and San Diego, California and Forth Worth, Texas (USA)	Linear	Residential
Nieswiadomy and Molina	1988	Growth and Change	Panel data (household data)	Monthly (Summer months, 1981-1985; June-September 1981-1983, May-October, 1984-1985)	OLS, IV, 2SLS	2702 (from 104 customers and the summer months of 5 years)	Denton, Texas (USA)	Linear	Residential
Palencia	1988	Water Resources Bulletin	Time Series (Aggregate)	Annual (1970-1981)	OLS (corrected from 1st degree of autocorrelation)	11	Manila (Philippines)	Linear	Residential
Thomas and Syme	1988	Water Resources Research	Time-series (aggregate) and cross-section, household data for CV	Annual (1957/58-1985/86 for TS), 1982 (CV)	OLS (for time-series data) and Contingent Valuation	28 (TS); 312 (CV)	Perth Metropolitan Area, Western Australia (Australia)	Linear	Residential
Agthe and Billings	1987	American Journal of Economics and Sociology	Panel data (household data)	Monthly (1974-1981)	IV, Simultaneous equations	2673 to 7149 (depending on the income group)	Tucson, Arizona (USA)	Linear	Residential
Billings	1987	Water Resources Bulletin	Time-series (Aggregate)	Monthly (January 1974-December 1980)	OLS, IV, censored sample technique	84 (time-series); 1008 (panel: 12 districts*84 months)	Tucson, Arizona (USA)	Linear	Residential
Frerichs et al.	1987	University of Minnesota, Department of Applied Economics, Economic Report	Cross-section (aggregate)	Annual (1986)	OLS	92	Minnesota (USA)	Linear and double logarithmic (loglinear or log-log)	Residential

Authors	Year of publication	Where Published	Type of data	Periodicity	Econometric method	Number of observations	Study area	Functional form	Type of demand
Moncur	1987	Water Resources Research	Panel data (household data)	Bimonthly (1974-1981)	Panel data techniques	53802 (1281 households*42 bimonthly billing periods)	City and County of Honolulu, Hawaii (USA)	Linear	Residential
Schefter	1987	Land Economics	Cross-section (aggregate)	Annual (1979)	OLS	19 communities	Wisconsin (USA)	Linear	Residential
Agthe et al.	1986	Water Resources Research	Time-series (Aggregate)	Monthly (January 1974-December 1980)	OLS, IV, simultaneous equations	84	Tucson, Arizona (USA)	Linear	Residential
Chicoine and Ramamurthy	1986	Land Economics	Panel data (Household data)	Monthly (1982)	Pooled OLS	681 (1200 potential observations [12 monthly observations in 1982 *100 sampled customers], but consumptions in the 1st block and where uniform prices apply were discarded)	Illinois (rural areas) (USA)	Linear	Residential
Chicoine et al.	1986	Water Resources Research	Panel data (Household data)	Monthly (1982)	OLS, IV, 2SLS, 3SLS, Simultaneous equations	641 (648 potential observations: 54 monthly observations in 1982 * 54 households; consumptions in the 1st block were discarded)	Illinois (rural areas) (USA)	Linear	Residential
Deller et al.	1986	Southern Economic Journal	Panel data (Household data)	Monthly (1982)	OLS, IV (2SLS)	641 (648 potential observations [12 monthly observations in 1982 *54 sampled customers], but consumptions in the 1st block are discarded adding to missing data andobservations discarded for measurement problems)	Illinois (rural areas) (USA)	Linear	Residential
Martin and Thomas	1986	Water Resources Research	Cross-section (household data)	Annual (1978/79 or 1981/82)	OLS	5	Perth, Western Australia; Coober Peddy, South Australia (Australia); Tucson and Phoenix, Arizona (USA); Kuwait	Double logarithmic (loglinear or log-log)	Residential
Williams and Suh	1986	Applied Economics	Cross-section (Aggregate)	Annual (1976)	OLS	86	USA	Linear and double logarithmic (loglinear or log-log) (logarithmic chosen based on R2)	Residential, commercial and industrial
Al-Qunaibet and Johnston	1985	Water Resources Research	Time-series (Aggregate)	Monthly (January 1973-December 1981)	ML	96	Kuwait	Linear, double logarithmic (loglinear or log-log), Semilogarithmic (lin-log and log-lin) and Stone-Geary	Municipal
Cochran and Cotton	1985	Water Resources Research	Time-series (Aggregate data)	Annual (1961-1980)	OLS	20	Oklahoma City and Tulsa, Oklahoma (USA)	Linear and double logarithmic (loglinear or log-log)	Municipal

Authors	Year of publication	Where Published	Type of data	Periodicity	Econometric method	Number of observations	Study area	Functional form	Type of demand
Schefter and David	1985	Land Economics	Cross-section (aggregate)	Annual (1979)	OLS	131	Wisconsin (USA)	Linear	Residential
Jones and Morris	1984	Water Resources Research	Cross-section (household data)	Annual (1976)	IV	326	Metropolitan Area of Denver, Colorado (USA)	Linear, double logarithmic (loglinear or log-log), Semilogarithmic (log-lin)	Residential
Young et al.	1983	Water Resources Bulletin	Panel data (Household data)	Quarterly (1974-1977)	RE	8720 (545 households*16 quarters)	Washington D.C. (USA)	Linear	Residential
Billings	1982	Land Economics	Time Series (Aggregate)	Monthly (January 1974-September 1977)	IV	45	Tucson, Arizona (USA)	Linear; double logarithmic (log-linear or log-log)	Residential
Hanke and de Maré	1982	Water Resources Bulletin	Panel data (household data)	Semiannualy (last period of 1971 to first period of 1978)	OLS	959 observations in a potential of 966 (69 households, studied semi-annualy, over 14 time periods)	Malmö (Suécia)	Linear	Residential
Howe	1982	Water Resources Research	Cross-section (Aggregate)	Intra-Annual (1963-1965)	OLS	21	USA	Linear	Residential
Ford and Ziegler	1981	The Annals of Regional Science	Cross-section (household data)	-	OLS	1770	Arkansas (USA)	Semilogarithmic (log-lin)	Residential
Foster and Beattie	1981	Land Economics	Cross-section (aggregate)	Annual (1960)	OLS	218 cities	USA	Semilogarithmic (log-lin)	Residential

Authors	Year of publication	Where Published	Type of data	Periodicity	Econometric method	Number of observations	Study area	Functional form	Type of demand
Agthe and Billings	1980	Water Resources Research	Time Series (Aggregate)	Monthly (-)	OLS	45	Tucson, Arizona (USA)	Static: linear, Fisher-Kaysen; Dynamic: Koyck distributed lag model, Bergstrom model or flow adjustment model (linear and logarithmic)	Residential
Ben-zvi	1980	Report - U.S. Army Corps of Engineers	Cross-section (aggregate: nonindustrial; firm data: industrial)	Monthly (1978)	OLS	20 (nonindustrial); 84 (industrial plants)	Red River Basin, Tulsa, Oklahoma (USA)	Double logarithmic (loglinear or log-log)	Industrial and non-industrial
Billings and Agthe	1980	Land Economics	Time Series (Aggregate)	Monthly (January 1974-September 1977)	OLS	45	Tucson, Arizona (USA)	Linear; double logarithmic (log-linear or log-log)	Residential
Carver and Boland	1980	Water Resources Research	Panel data (Aggregate)	Monthly (1969-1974)	OLS and LSDV (FE)	376 (nonseasonal); 373 (seasonal) (from unbalanced panels of 13 utilities * 30 months)	Washington D. C. (USA)	Linear	Municipal
Cassuto and Ryan	1979	Water Resources Bulletin	Panel data (aggregate)	Monthly (1970-1975)	OLS	19008 (264 census tracts*72 months)	Oakland, California (USA)	Linear and double logarithmic (loglinear or log-log)	Residential
Colander and Haltiwanger	1979	Water Resources Research	Time-series (Aggregate)	Annual (1946-1971)	OLS (corrected from 1st degree of autocorrelation)	26	Tucson, Arizona (USA)	Double logarithmic (loglinear or log-log)	Residential
Danielson	1979	Water Resources Research	Panel data (Household data)	Monthly (May 1969-December 1974)	OLS	17748 (261 households*68 months)	Raleigh, North Carolina (USA)	Double logarithmic (loglinear or log-log)	Residential
Foster and Beattie	1979	Land Economics	Cross-section (aggregate)	Annual (1960)	OLS	218 cities	USA	Semilogarithmic (log-lin)	Residential
Camp	1978	Journal of the American Water Works Association	Cross-section (Household data)	Monthly (-)	OLS	288	Northern Mississipi (USA)	Linear, double logarithmic (loglinear or log-log) and semiligarithmic (log-lin and lin-log)	Residential
Gibbs	1978	Water Resources Research	Panel data (Household data)	Quarterly (1973)	OLS	1412 (355 households*4 quarters)	Miami, Florida (USA)	Semilogarithmic (log-lin)	Residential

Authors	Year of publication	Where Published	Type of data	Periodicity	Econometric method	Number of observations	Study area	Functional form	Type of demand
Katzman	1977	Water Resources Bulletin	Cross-section and panel data (household data)	Quarterly (1972) and bimonthly (May 1970-November 1975)	OLS	1400 (for quarterly croos-section)	Penang Island (Malaysia)	Linear	Residential
Clark	1976	Journal of the Environmental Engineering Division	Cross-section (aggregate)	Annual (-)	OLS	22	Cincinnati, Ohio (USA)	Linear, double logarithmic (loglinear or log-log), inverse, exponential, inverse semilog	Municipal
Grunewald et al.	1976	Water Resources Bulletin	Cross-section (aggregate)	Annual (1972)	OLS	150 rural water districts	Kentucky (USA)	Linear; double logarithmic (loglinear or log-log)	Residential
Morgan and Smolen	1976	Water Resources Bulletin	Cross-section (aggregate)	Monthly (-)	OLS	396 (33 cities * 12 months)	Southern California (USA)	Linear	Municipal
Andrews and Gibbs	1975	Southern Journal of Agricultural Economics	Panel data (Household data)	Quarterly (1973)	OLS	1420 (4 quarters * 355 sampled households)	Dade County, Metropolitan Miami, Florida (USA)	Semilogarithmic (log-lin)	Residential
Attanasi et al.	1975	Report - U.S. Department of Interior	Panel data (Aggregate)	Annual (1960-1971)	OLS and RE	143 (13 municipalites*11 years)	San Juan, Puerto Rico (USA)	Linear	Residential, commercial and industrial
Batchelor	1975	Land Economics	Cross-Section (household data)	Annual (1968)	GLS	698	Malvern, Worcestershire (UK)	Linear	Residential
Darr et al.	1975	Water Resources Research	Cross-section (Household data)	Annual (1970/1971)	OLS	1892	Jerusalen, Tel Aviv, Haifa and Beersheva (Israel)	Linear and double logarithmic (Log-linear or log-lo-log)	Residential
Hogarty and MacKay	1975	Water Resources Research	Panel data (household data)	Quarterly (1971(4)-1973(4))	OLS	1080 (120 households * 9 quarters)	Blacksburg, Virgina (USA)	Linear	Residential
Morgan	1974	Water Resources Bulletin	Time-series (individual data)	Bimonthly (1968-1971)	OLS	816 (34 households * 24 bimonthly billing periods) [31 for the 2nd regression, 30 billing periods 1967-1972 (February)]	Goleta County Water District, Santa Barbara, California (USA)	Linear	Municipal

Authors	Year of publication	Where Published	Type of data	Periodicity	Econometric method	Number of observations	Study area	Functional form	Type of demand
Grima	1973	Water Resources Bulletin	Cross-section (household data)	Intra-annual (-)	OLS	102	Toronto (Canada)	Double logarithmic (loglinear or log-log)	Residential
Morgan	1973	Water Resources Research	Cross-section (household data)	Bimonthly (-)	OLS	92	Santa Barbara County, California (USA)	Linear and double logarithmic (Log-linear or log-lo-log)	Residential
Young	1973	Water Resources Research	Time-series (Aggregate)	Annual (1946-1971)	OLS	26	Tucson, Arizona (USA)	Linear; double logarithmic (loglinear or log-log)	Municipal
Wong	1972	Land Economics	Time-series and Cross-section (aggregate)	Annual (1951-1961)	OLS	11 (time-series), 103 (cross section; stratified into 4-community size groups with 15 to 40 observations each)	Chicago, Northeastern Illinois (USA)	Double logarithmic (loglinear or log-log)	Municipal
Hanke and Davis	1971	Journal of the American Water Works Association	Cross-section (aggregate)	Intra-annually (1969)	OLS	-	Washington D.C., District of Columbia, Fairfax County, Virginia and Maryland (USA)	Double logarithmic (loglinear or log-log)	Residential and Commercial/ industrial
Hanke	1970	Water Resources Research	Time-series (Aggregate)	Monthly (1955-1968)	OLS	168	Boulder, Colorado (USA)	Linear	Residential
Turnovsky	1969	Water Resources Research	Cross-section (Aggregate)	Annual (separate regressions for 1962 and 1965)	OLS	19	Massachussets (USA)	Linear	Residential and industrial/services
Meroz	1968	WP - International Bank for Reconstruction and Development, Economics Department	Cross-section (Aggregate)	Annual (1957 to 1965, depending on observation)	OLS	38	Africa, Asia, Latin America	Linear; double logarithmic (loglinear or log-log)	Residential and other
Conley	1967	The Annals of Regional Science	Cross-section (Aggregate)	Annual (1955)	OLS	24	Southern California (USA)	Double logarithmic (loglinear or log-log)	Residential
Howe and Linaweaver	1967	Water Resources Research	Cross-section (Aggregate)	Intra-Annual (1963-1965)	OLS	39	USA	Linear; double logarithmic (loglinear or log-log)	Residential
Bain et al.	1966	Book published by Johns Hopkins Press	Cross-section (Aggregate)	Annual (1955)	OLS	41	Northern California (USA)	Double logarithmic (loglinear or log-log)	Municipal
Flack	1965	PhD thesis - Stanford University	Cross-section (Aggregate)	Annual (-)	OLS	54	USA	Linear	Municipal

Authors	Year of publication	Where Published	Type of data	Periodicity	Econometric method	Number of observations	Study area	Functional form	Type of demand
Gardner and Schick	1964	Bulletin - Agricultural Experiment Station, Utah State University	Cross-section (Aggregate)	Annual (-)	OLS	43	Utah (USA)	Linear; double logarithmic (loglinear or log-log)	Municipal
Gottlieb	1963	Land Economics	Cross-section (Aggregate)	Annual (1957)	OLS	70 (12 Illinois, 24 Kansas, 34 USA)	Kansas and Illinois (USA)	Double logarithmic (loglinear or log-log)	Municipal
Headley	1963	Land Economics	Time-series and Cross-section (aggregate)	Annual (1950-1959)	OLS	10 (time-series); 14 (cross-section)	San Francisco-Oakland Metropolitan Area (USA)	Linear, semilogarithmic (log-lin)	Residential and Commercial
Fourt	1958	Unpublished paper - Agricultural Economics Seminar, University of Chicago	Cross-section (Aggregate)	Annual (1955)	OLS	34	Southern California (USA)	Double logarithmic (loglinear or log-log)	Municipal
Seidel and Baumann	1957	Journal of the American Water Works Association	Cross-section (Aggregate)	Annual (1955)	OLS	111	USA	Linear	Municipal
Larson and Hudson	1951	Journal of the American Water Works Association	Cross-section (Aggregate)	Annual (1948)	OLS	15	Illinois (USA)	Linear	Residential
Metcalf	1926	Journal of the American Water Works Association	Cross-section (Aggregate)	5 year-averages (1920-1924)	OLS	29	USA	-	Municipal

Authors	Year of publication	Dependent variable - water consumption / demand	Explanatory variables				
			Price	Income	Household size	Weather	Others
Bartczak et al.	2009	Daily per capita water consumption	X (including wastewater charges)	Average net income per capita	X	-	Year dummies
Diakité et al.	2009	1st stage: proportion of users per block; 2nd stage: average water use per account per year	2nd stage: average/weighted AP (the weights are proportion of users per block)	X	-	-	Unpaid volumes per household; % of subsidized new customers; access to water/1000 individuals; network rate of return; number of customers
Garcia-Valiñas et al.	2009	Average consumption per household	AP	Average taxable income	X	-	Regional indicator; Share of apartments in the total population of residences; dummies for urban or touristic zones; temporal dummies)
Olmstead	2009	Average daily water demand in each of the two week periods (arid and wet season)	MP (Instruments used for MP in the IV model: twelve instruments representing the "marginal price of consuming thousand-gallon increments of water — as many increments as the price variation in the data will allow: 1, 2, 3, 5, 6, 8, 10, 20, 30, 40, 50, and 75 thousand gallons"; "monthly fixed fees charged to water consumers"; "exogenous covariates from the water demand model")	Virtual income (difference between the unadjusted income and the difference variable from the Taylor-Nordin specification)	X	maximum daily temperature, the moisture requirement of lawns (evapotranspiration, less 0.6*measured precipitation), dummy variable set equal to one during the outdoor watering season.	Lot size, square footage of homes, home age, number of bathrooms, dummy variable for evaporative air cooling (which substitutes water for electricity in air conditioning). Dummy variables that represent the seven urban areas in the data
Ruijs	2009	per capita consumption of water (m3/month)	MP (3rd block price) and difference (Taylor-Nordin specification)	Per capita income	-	average temperature; precipitation; lagged precipitation	Dummy for whether rationing occurred; lagged consumption
Schleich	2009	Average water use per capita per day	AP (including sewage tariffs)	Average net income of private households per capita	X	Rainfall (average number of days with rainfall >1mm in spring and summer months: April-September) and average temperature during the spring and summer months	Average population age; share of households served with wells; regional dummy variables; share of single-family households
Schleich and Hillenbrand	2009	Average water use per capita per day	AP (including sewage tariffs)	Average net income of private households per capita	X	precipitation (average number of days with precipitation >1mm in spring and summer months: April-September) and average temperature during the spring and summer months	Average population age; share of households served with wells; regional dummy variables; share of single-family households
Arbués-Gracia et al.	2008	Average daily water consumption in the quarter (in logs)	MP (t-2)	Registered real estate value of the property	Different regressions are performed for each household size	Dummy variable for temperature (1 if greater than 18.ºC, 0 otherwise)	Common central heating (common water use)
Azomahou	2008	Average annual water consumption per household (includes water losses in the network)	AP	X (Annual average disposable income divided by two)	-	precipitation, Mean temperature	AP of electricity; % of population with 19 years or less of age; household density (households/hectare); proportion of employess; proportion of unemployed; index of equipment (showers + toilets + bath-tubs / population * 100)

Authors	Year of publication	Dependent variable - water consumption / demand	Explanatory variables				
			Price	Income	Household size	Weather	Others
Basani et al.	2008	Monthly household water consumption	MP; connection fee (selection model)	Household expenditure	X	-	Location dummies; connection dummy; dummies for house equipment ownership; education level dummies; age of the head of household; time that the head of household has lived in the house; % household members earning income; dummies for customer satisfaction with water quality and service reliability; dummies for several water uses; dummy for shared connections and for water clearity
Bell and Griffin	2008	Daily per capita water supplied	MP and AP (including sewerage charges)	Monthly personal income	-	Average minimum and maximum temperature and days in month with no precipitation	-
Cheesman et al.	2008	Monthly household water consumption (separate regressions for households using only a private connection and using both a private connection and a well)	X	Household income	X	-	Dummy for knowledge of the water price (alone and interacted with the price), farming households, households running a business and use of storage tank. Storage capacity
Frondel and Messner	2008	Household water consumption	X (including sewer charges)	Household income	-	Temperature and precipitation	Age of survey respondent. Dummies for: sex of respondent; house-type (one family); dishwasher; swimming pool; high outdoor water consumption; if respondent stated that saving water conserves the environment; if respondent stated that saving water saves money; respondent has correctly indicated the broad range of prices
Kenney et al.	2008	Household consumption per billing period	AP (instrumented)	Median household income	X	Total precipitation and average daily maximum temperature	Dummy variable for: the existence of use restrictions during the billing period (also interacted with AP); household's participation in the outdoor rebate program for the implementation of water efficient technologies; purchase of a water smart reader; irrigation season (May-October); Christmas of Thanksgiving during the billing period. Length of the billing period; Median age of homeowner; % of homes owner occupied; % of homes built prior to 1970; % of homes built after 1991; median number of bedrooms; dummy variable for the existence of IBT
Miyawaki et al.	2008	Total water consumed	X (includes sewage charge)	X (virtual income)	X	-	Number of rooms in house/apartment; total floor space of house/apartment; lagged dependent variable on one of the models
Nataraj and Hanemann	2008	Household water consumption (1 observation = 2 months)	MP	X (used to test the difference between control and treatment groups)	X (used to test the difference between control and treatment groups)	Maximum temperature, evapotranspiration minus precipitation	Treatment dummy; dummy variable for 1995; Variables used to test the difference between control and treatment groups: average age of residents; house age; number of rooms and bedrooms; housing density ina given area as a proxy for lot size; population density and % of owned houses in a given area

Authors	Year of publication	Dependent variable - water consumption / demand	Explanatory variables				
			Price	Income	Household size	Weather	Others
Nauges and Berg	2008	Piped and non-piped household water demand	MP and AP (instrumented by household location dummies); time cost for getting water from non-piped sources	Monthly household income	X	-	Number of rooms; dummy for the use of a storage tank; years of education of the head of household; regional dummies; number of hours of piped water availability; dummy variables regarding taste, reliability, and safety of water from private wells, use of an electric pump and household's ethnicity (for the non-piped water demand equation)
Reynaud	2008	Water consumption per day (different regressions for peak and off-peak)	AP. Unit price (including taxes) per cubic meter for an annual water consumption equal to 120 cubic meter (unit price is obtained by dividing the total bill by the water consumption)	X (representative household's income)	X	Values for summer and fall for the following variables: daily minimal temperature; daily maximal temperature; daily solar radiation; Penman's PET (potential evapotranspiration); daily rain	number of consumption units per household; dummy for nitrate vulnerable area; dummy if tourist area; population density; share of water from groundwater sources; share of water from surface sources; share of seasonal population; ratio of domestic to other water users; share of permanent housing; share of collective housing; share of rivers classified as bad quality within a given local community
Ruijs et al.	2008	per capita consumption of water (m3/month)	MP and difference, and AP (instrumented from the block prices)	Per capita income	-	average temperature; precipitation; lagged precipitation	Dummy for whether rationing occurred; time trend; lagged consumption
Statzu and Strazzera	2008	Average annual water consumption per household	AP	Average household taxable income	X	Summer evapotranspiration rate	Town's tourist specialization level; number of hours of regular water distribution; % population not in the labour force; % of home owners; % of dwellings that have not been refurbished in the period; town altitude; dummies for different utilities; year dummies
Strong and Smith	2008	Average monthly household water consumption	MP	X	-	Temperature and precipitation	% of houses with pools; total number of lots in the service area, number of rental units
Xayavong et al.	2008	Household water consumption	MP and difference (weighted means using proportions of users per block estimated from climate data, demographic factors and housing characteristics)	Virtual income and real income	X	Summer (November-April) precipitation and summer cooling-degree-days	% of home owners and renters; % people >65 and <19 years; bores/user accounts; average lot size
Babel et al.	2007	Total daily domestic water use	AP (average water tariff rate after minimum allowance of water supply ($10m^3$/month))	Per capita GDP (current prices) (dropped because of multicollinearity)	Average household size (dropped because of multicollinearity)	Average annual temperature (dropped because it was not significant); annual precipitation	Number of connections; population (dropped because of multicollinearity); ratio of the total population to the university students; number of households (dropped because of multicollinearity)
Dahan and Nisan	2007	Annual household water consumption	MP (highest price paid during the year) and difference (Taylor-Nordin specification)	Dummy for households below poverty line	Dummy variables for the several household sizes	-	Apartment size; lawn size; number of apartments in the building; regional dummy variable; dummies for tax reliefs
Fullerton et al.	2007	Per customer water consumption (a regression for the number of customers is also performed)	AP (including sewage charges)	-	-	Precipitation, average temperature	Monthly maquiladora employment; National industrial production index for Mexico
Grafton and Kompas	2007	Aggregate daily water demand	X	-	X	Daily temperature; daily precipitation	Dummy variable to account for reductions in demand following the introduction of water restrictions
Grafton and Ward	2007	Aggregate daily water demand	X	-	-	Daily precipitation (current and lagged); maximum daily temperature (current and lagged)	Water restrictions - two dummy variables (from November 1994 to October 1996, and from October 2003 to the end of the sampling period)

Authors	Year of publication	Dependent variable - water consumption / demand	Explanatory variables				
			Price	Income	Household size	Weather	Others
Mansur and Olmstead	2007	Daily household water demand (total, indoor and outdoor)	MP	Virtual income (income + difference)	X	Dummy variable for season (arid vs. wet); maximum daily temperature; evapotranspiration less effective (0.6) precipitation	Household lot size; size and age of homes; number of bathrooms; presence of evaporative cooling; regional dummies
Martínez-Espiñeira	2007	Average per capita monthly domestic water use.	MP and difference (Taylor-Nordin specification) (difference used to calculate virtual income; see income)	Virtual income (difference between the average salaries and the difference variable from the Taylor-Nordin specification)	-	Precipitation (monthly); Temperature (average of daily maximum temperatures in the month)	Water restrictions ("number of daily hours [weighted by the number of days in a month] of supply restrictions applied as part of the emergency control measures during the worst drought periods."); dummy variable for temporary outdoor-use bans; dummy variable for periods when "water conservation information campaigns were being applied during the drought"; dummy variable for the months of May, June, July and August
Martins and Fortunato	2007	monthly water demanded per typical (representative) household in a local community (standardized into monthly equivalents)	MP and difference (Taylor-Nordin specification) (instrumentes from a linear approximation to the total water bill) (sewage rates considered with water prices when applicable)	automatic teller machines withdrawals per capita (deflated and used as a proxy for the income variable)	X	Precipitation (Normal monthly precipitation) and temperature (Normal maximum monthly air temperature) (from AGRIBASE) (The values used for these variables are their normal values per month, computed as historical (long-term) averages for a period of 30 years).	Dummy variable, which takes the value 1 in the case that only one block price applies to every cubic metre consumed and the value 0 if several block prices are applied; percentage of people over 65
Musolesi and Nosvelli	2007	Average annual household water consumption	AP	Average per capita income	X	-	% of population > 65 years of age; lagged consumption; % of commercial entreprises
Nauges and Strand	2007	1st step: selected water source (private tap; public weel; truck; public tap is the comparison group); 2nd step: total water consumption (including free water) per capita per month	2nd step: Total costs per cubic meter (marginal price + monetized hauling cost)	X (1st and 2nd step)	1st step: Number of households in residence; 2nd step: household size	-	1st step: Lot size; constructed area; access to electricity; "interviewee reads and writes"; number of children less than five; 2nd step: lot size; money saving due to having access to free water

Authors	Year of publication	Dependent variable - water consumption / demand	Explanatory variables				
			Price	Income	Household size	Weather	Others
Olmstead et al.	2007	Daily household water demand	MP	X	X	Evapotranspiration less effective precipitation; Maximum daily temperature; dummy variable set equal to one during the arid (peak outdoor watering) season	Lot size; Square footage of homes; number of bathrooms; Home age; Dummy variable for price structure (IBT vs UP); Evaporative cooling in air conditioning (uses water instead of electricity); Dummy variable for city specific effect
Yoo	2007	Natural logarithm of the household's monthly tap water demand	AP (natural logarithm of average price)	X (natural logarithm of the monthly income of the household)	X	-	number of people in the household whose age is over 65; dummy for the types of dwelling units; dummy for the household's judging whether or not the tap water is suitable for drinking, dummy for the household's currently using the tap water for drinking; dummy variable for city specific effect; Monthly bottled water expenditure of the household; Frequency of the household's visiting spring for getting potable water; dummy for the household's house being equipped with water-conserving tools.
Arbués and Villanua	2006	Daily water consumption in each billing period (converted from a nearly quarterly billing period; from 63 to 114 days between readings)	AP lagged 2 periods (2 quarters) (2 specifications: including or excluding the fixed charge) (the inclusion of the fixed charge is chosen as best based on the Schwarz BIC criterion of model selection)	Proxy variable for income: average earnings in the Autonomous Community of Aragon of a worker with the age and educational level of the head of the household.	X	Dummy variable for average daily maximum temperature (1 if > 18.ºC)	Availability of a commom hot water facility in the building
Fullerton et al.	2006	Water consumption per user	AP	Maquiladora employment; industrial production	-	Precipitation, average temperature	-
Garcia-Valiñas	2006	Quarterly household/firm water consumption	AP lagged two quarters for households and one quarter for businesses (alone and interacted with dummies for the block of consumtpion or the type of meter)	Property value based on street location (proxy for household income); dummies for the type of business as proxy fot the level of economic activity (commercial/ industrial)	X	-	Lagged water consumption (1 quarter for households, 4 quarters for firms); number of hours of supply per period; dummy variable for the deterioration of water pressure or quality; yearly dummies
Gaudin	2006	Per capita annual water consumption	AP; AP interacted with several dummy variables (if MP is indicated next to the units consumed; if MP is indicated next to the units consumed or if the full price schedule is shown; when the bills include consumption history or daily average use; if sewer, electricity and/or gas charges were included in the same bill; if the frequency of billing is monthly; if there was an IBT).	X	X	Average annual precipitation (30-year average); number of days when temperature exceeded 90 ºF (32,(2) ºC)	Population density; Dummy variable for the inclusion of water conservation messages in the water bills

Authors	Year of publication	Dependent variable - water consumption / demand	Explanatory variables				
			Price	Income	Household size	Weather	Others
Hoffmann et al.	2006	Average quarterly household water consumption (regressions performed for three separate groups: all households, owner-occupied households and rental households)	MP	X	X	Number of rainy (>0 mm) and warm days ("daily maximum in the uppermost quartile of all daily temperatures"; "effective cut-off is temperatures greater than 28.5°C")	Dummy for summer quarter; Lagged demand (previous quarter)
Jansen and Schulz	2006	Monthly household water consumption	MP and difference (Taylor-Nordin specification) (instrumentes from a linear approximation to the total water bill and other exogenous variables)	Dummies for income categories	X	Maximum temperature and precipitation	Dummies for the existence of bath/shower, garden, washing machine, year restriction dummies; average age of the household; interaction between marginal price and income categories dummies
Kostas and Chrysostomos	2006	Annual residential water demand	X	Real per capita GDP	-	-	Trend; dummy variables for 1992 and 1994
Larson et al.	2006	Monthly household water use	-	Dummies for income categories	X	-	Dummy for water source (private connection or otherwise); Dummies for head of household's education level; roundtrip walking time to water source; average waiting time at water source; dummy for households that improve water quality before consuming
Mazzanti and Montini	2006	Per capita water consumption	Price of the medium block	Income per capita	X	-	% of population <= 19 years; % of population >= 65 years; population density; number of water users; % of municipal rural area; elderly ratio; altitude
Carter and Milon	2005	Monthly household water consumption	MP and AP	X	X	Precipitation and mean temperature	Lagged consumption; Knowledge on the price of 1000 gallons of water; dummy for own residence; house age; lawn size; dummy variables for dishwasher; irrigation well, only for probit decision model: location dummies, dummy for bottled water drinking, knowledge about low-flow fixtures and xeriscaping
Dalmas and Reynaud	2005	Water consumption per year per capita	X (includes sewerage charge)	Employee wages as a proxy for real income	X	Precipitation (average monthly precipitation from April to September) and Temperature (average monthly temperature from March to September)	Unemployment rate; average number of rooms per dwelling; % of dwellings equipped with an automatic washing machine; average number of square meters of living floor space; % of dwellings used for recreation
Garcia-Valiñas	2005	Quarterly household/firm water consumption	AP lagged 1 period (instrumented from the fixed charge, the difference between MP and the lowest block price and rainfall)	Property value based on street location (proxy for household income); dummies for the type of business as proxy fot the level of economic activity (commercial/ industrial)	X	Precipitation (used in the instrumentation of AP)	Number of supplied hours in the period; dummy variables for the cases where water pressure or quality was below normal levels in the current or previous period; dummy variables for the existence of collective metering (residential); number of unemployed people in the sector (commercial / industrial)
Garcia-Valiñas	2005	Quarterly household/firm water consumption	AP lagged 2 periods for households and 1 period for firms	Real estate value of the house as proxy for income	X	Average maximum daily temperature and total precipitation	Lagged water consumption (1 quarter for households, 4 quarters for firms); Firms: dummies for type of economic activity, street location dummies and annual dummies; Households: dummies for consumptions in the first and second blocks

Authors	Year of publication	Dependent variable - water consumption / demand	Explanatory variables				
			Price	Income	Household size	Weather	Others
García-Valiñas	2005	Bimonthly household/firm water consumption	AP lagged 2 periods for households; lagged 1 period for commercial/industrial customers	Real estate value of the house as proxy for income. For firms, type of business dummies and location were used as proxies for the level of activity	X	Average maximum daily temperature and total precipitation	Lagged consumption (lagged one period for households; lagged one year for commercial/industrial customers); dummy for houses with collective metering. For firms year dummies were used.
Gaudin	2005	Per capita water consumption	AP; AP interacted with several dummy variables (if unit price information apperas on the bill; when the bills include consumption history or daily average use; if other relevant quantity information is shown; if sewer, electricity and/or gas charges were included in the same bill; if there was an IBT).	X	X	Average annual precipitation (30-year average); number of hot days (when temperature exceeded 90°F (32.2ºC) during the survey year)	Population density; Dummy for water conservation messages in the water bill
Hanemann and Nauges	2005	Average daily water consumption	X	Median income, median value of the house	-	Average maximum temperature and total precipitation	Dummy variables for the periods where a voluntary and a mandatory conservation programmes took place; lot size category; % of households with specific education levels, house vintage, % of housing units with more than 7 rooms, and number of owned versus rented housing units; % housing units built between 1960 and 1980; % housing units built between 1980 and 1990
Martins and Fortunato	2005	Monthly average household water consumption	MP (instrumented by the 3 first block prices, remaining exogenous variables, number of meters and % of water losses) and difference	X	X	Temperature, precipitation	Populational density
Reynaud and Thomas	2005	Annual average household water consumption (two separate equations for direct and delegated management)	AP for a monthly consumption od 100 m3 (including sewerage)	Municipal income taxes per household	-	Precipitation in the summer months (June, July and August)	% of new dwellings; % of population >75 years; population density; % of workforce working at home (to account for water consumption of craftsmen and liberal workers); % of principal dwellings; % of households in collective buildings, existence of municipal associations and network efficiency; (also for the selection model); For the selection model of water utility type: real estate value of the houses, according to location; % of old dwellings; area of the municipality; location dummies; customers/population; existence of autonomous sewerage; aquisition of all raw water from a bulk provider; average water bill; proportion of industrial consumption; number of water boreholes; ratio of peak consumption to mean consumption; average household water consumption; network length per customer;

Authors	Year of publication	Dependent variable - water consumption / demand	Explanatory variables				
			Price	Income	Household size	Weather	Others
Reynaud et al.	2005	Monthly water consumption of the representative household (separate regressions for different pricing structures); Regression model for the choice of the pricing structure	MP (including sewage charges) (instrumented from the "marginal price for 10, 25 and 35 m3/month, the upper bound of the first block, the lower bound of the last block, the number of blocks and some socioeconomic variables describing the average household" when IBR or DBR are implemented); AP used for the flat fee cases	X	-	-	Inverse of Mill's ratio from the pricing structure choice model; Regressors used for the water demand model and for the pricing structure choice regression: average biochemical oxygen demand (BOD) of influents and effluents, the share of groundwater in total water supply, the share of the population without any sewage plant; dummies for the existence of treatment or disinfection prior to water use; unemployment rate, the share of the population without any earned income and the ratio of the domestic water consumption to the total water consumption; ratio of the difference between median and average incomes to the average income, standard error of the average income; share of rural population; categorical variable representing the size of the municipality; average number of room per dwelling; share of dwellings built before 1946 (or after 1991); share of individual houses; number of days with restriction in use (or in boil) in 1993, 1995 and 1998; number of years with water quantity (or quality) problems; population density; population change between 1991 and 1996; pro
Strand and Walker	2005	Monthly household water consumption	MP and Difference (Taylor-Nordin specification) AP (all instrumented); water price and hauling costs for nontap water	Income and value of the house	Number of adults and number of children (tap water); household size (nontap water)	-	Existence of telephone; City dummies; dummies for the number of daily service hours
Arbués et al.	2004	Daily household water consumption	AP (lagged 2 periods, with and without the fixed charge); Daily expenses (also lagged 2 periods); MP	Property value (proxy for income)	X	-	Availability of common hot water facility (with a separate common meter)
Fullerton and Elías	2004	Monthly consumption per connection	AP	Non-agricultural employment used as a proxy for economic conditions	-	Precipitation, number of days with preciptation and the number of days with temperatures above 90° Fahrenheit	-
Garcia and Reynaud	2004	Water consumption per customer	MP	X	X	Summer precipitation	% of housing not equipped with a bath or toilet, % of housing with less than 8 years old; average number of employees per industrial firm; proportion of firms operating in the electricity, gas, water and construction sector; proportion of industrial users

Authors	Year of publication	Dependent variable - water consumption / demand	Explanatory variables				
			Price	Income	Household size	Weather	Others
Martínez-Espiñeira and Nauges	2004	Water consumption per capita	MP (includes wastewater charges) ("instrumental marginal price derived from a linear regression of the theoretical water bills associated with all integer values of monthly water use per account between 1 m3 and 25 m3", the slope of the estimated function)	Virtual income (average salaries - difference (Taylor-Nordin specification)) ("instrumental difference derived from a linear regression of the theoretical water bills associated with all integer values of monthly water use per account between 1 m3 and 25 m3", the intercept of the estimated function)	-	Precipitation in month t (historical averages for the period 1961–1990)	Number of daily hours of water supply restrictions during drought periods (weighted by the number of hours in the month); dummy variable with value 1 when temporary outdoor-use bans were applied during the drought; Population; Lagged average past consumption used in the model with varying threshold
Mylopoulos et al.	2004	Household water consumption (1 observation = 2 months)	MP and AP (separate regressions for each - marginal price specification is found to be superior)	Proxy variable for income derived from the regression of income on type of dwelling; coded floor of the building; residence surface area; dummy for property ownership; dummy for swimming pool ownership; dummy for WTP for improved service; dummies for wether the head of the household finds the water rates low-priced, reasonable or expensive; dummy for municipality	Number of household residents	Precipitation (four months sum); Temperature (four months average temperature)	Dummy variable for employees of the water authority; Temporal dummy variables to account for three periods with different tariffs; dummies for families with more than 4 children; type pf dwelling dummy (1 for apartment); dummy for car washing; dummy for watering plants; dummy for cleaning balconies; dummy for cleaning pavements;
Taylor et al.	2004	Monthly per capita water consumption	MP and AP (estimated simultaneously from consumption per capita, number of connections, customer density (customer/population), dummy variables for tariff types, and blocks	X	-	Monthly precipitation and highest annual temperature	Dummy for water conservation programs; dummy for summer months (June, July, August and September); dummies for tariff types (uniform pricing, IBT, DBT and fixed monthly charge)
Ayadi et al.	2003	Quarterly average household water consumption (one regression for each block of consumption (with one observation in each region and period for each block); and an additional regression of the proportion of users in each block on all explanatopry variables except income)	AP, AP instrumented by MP, AP calculated based on share of consumers in each block	Average household income	-	precipitation	Size of the distribution network; quarterly dummies; regional dummies for the model combining all observations
Dalhuisen et al.	2003	Price-elasticity of water demand; Income-elasticity of water demand	MP vs AP vs Shin price or price perception; Inclusion of difference variable; Types of tariff structures	Income included; GDP per capita of the region	X	Evapotranspiration, precipitation and temperature	Long-run vs. Short-run; West USA vs. East USA vs. Europe vs. other; functional form; population density; seasonal dummies; lagged dependent variable; commercial use included; estimation techniques (OLS vs. DCC model vs. Other); data frequency; type of data (household vs. Aggregate; cross-section vs. panel data vs. other; winter vs. summer vs. annual); unpublished studies; time trend
Fullerton and Nava	2003	Total municipal water consumption	AP	Industrial Production	-	Average precipitation and Temperature	-

Authors	Year of publication	Dependent variable - water consumption / demand	Explanatory variables				
			Price	Income	Household size	Weather	Others
Garcia and Thomas	2003	Per capita water demand	AP (including wastewater charges)	-	-	-	-
Krause et al.	2003	Water consumption (amount of water withdrawn from a given stock) in a controlled experiment	AP	X	-	-	Age, education, dummy variable for whether the person had been in a experiment group which fully depleted its stock, gender, ethnicity, political affiliation, religious affiliation, risk preferences; dummies to distinguish workforce participants and retirees from students
Martínez-Espiñeira	2003	1st stage: proportion of users per block; 2nd stage: average water use per account per month	2nd stage: MP and difference (Taylor-Nordin specification), average/weighted MP and average/weighted difference (the weights are proportion of users per block)	1st and 2nd stages: Estimated family disposable income per capita (data in intervals)	-	1st and 2nd stages: Average temperature in each month	1st stage: % of population under the age of 19; % of population over 64 years of age; 2nd stage: % of population over 64 years of age
Nauges and Thomas	2003	Annual household water consumption	MP	X	-	-	Lagged consumption
Piper	2003	Average monthly household water consumption	AP	X	X	Temperature, precipitation	Water quality of water delivered measured in terms of annual average total hardness (mg of total calcium cabonate per liter of water) measured as a five-categories ordinal variable
Acharya and Barbier	2002	Water collected and Water purchased from water vendors	X	-	X	-	Children/adult ratio; occupation; dummies for water sources; water collection time; several interaction terms
Agthe and Billings	2002	Water use/apartment/month	MP	-	Number of bedrooms per apartment as a proxy for household size	-	Value per bedroom, apartment age, indoor water-saving devices; swwiming pools; vacancy rates (% of unoccupied apartments); dummy for drip with timer irrigation for nongrass landscaping
Hajispyrou et al.	2002	Share of water in household expenditure on nondurable goods	MP	household income	Number of adults	-	Dummies for: type of dwelling; type of ownership; year of completion of residence; kitchen, shower and toilet characteristics; running water; childrens' age; characteristics of the head of household's job and education; ownership of several water-using appliances. Age of the head of household. Dwelling area. Expenditures on: waste disposal and sanitary services; dwelling rent and insurance; water pump; domestic servant; gardener. Regional dummies.
Ipe and Bhagwat	2002	Per capita water consumption	AP, MP	Annual per capita income	-	weather variable (sum of the number of days with precipitation less than 0.1 inch during the months from April to October multiplied by the average monthly temperature for that month)	-

Authors	Year of publication	Dependent variable - water consumption / demand	Explanatory variables				
			Price	Income	Household size	Weather	Others
Martínez-Espiñeira	2002	Average monthly water use; Average monthly water use in excess of the free allowance; Average monthly water use in the summer	MP and difference (Taylor-Nordin specification) (instrumentes from a linear approximation to the total water bill) (includes sewage charges); AP for monthly use of 10m3, MP for monthly use of 10m3 and the difference between both	Per capita household disposable income	X	Number of rainy days; Average temperature	Size of the free allowance (after paying the fixed charge); % of population over 64; % of dwellings occupied as main residence; frequency of billing (number of billing periods in a year)
Nauges and Blundell	2002	Annual water consumption per household	block prices and block limits (nonparametric estimation); MP (for the remaining techniques; instrumented in 2 SLS and ML, like difference, from the block prices, the fixed charge, the income, house size, household size and the dummy for washing-machine ownership); squared prices and incomes and the interaction between income and price are used for an alternative ML model.	Virtual income (calculated from gross household income and the difference variable)	X	-	Residence size; dummy for washing-machine ownership
Pashardes and Hajispyrou	2002	Share of water in household expenditure on nondurable goods	MP (instrumented from the remaining exogenous variables)	X	Number of adults; number of children	-	Washing machine; dishwasher; area of the dwelling; shower and toilette (inside or outside); running water; head of household in agriculture; head of household retired; sewage system; regional dummies
Gaudin et al.	2001	Daily per capita water consumption	AP (including sewaerage charges)	Per capita income	-	Days with precipitation < 0.25 inches * average temperature; 60 year average annual precipitation	% of population of Spanish origin; dummy variables for month and year
Gunatilake et al.	2001	Monthly household water consumption	MP and Difference (Taylor-Nordin specification)	X	X	-	-
Higgs and Worthington	2001	Daily household water consumption	MP (instrumented from a the rate schedule values and the consumption quantities estimated from a regressioin of quantity on all explanatory variables except MP)	Income; Ratable value of the property	X	-	Seasonal dummy for summer; Dummy for year; 10 principal components from: pensioner status; number of times the lawn is watered per week; type of garden vegetation (native vegetation, vegetable crops); property and yard size; water absorbency of soil; number of car washes per week; dummy variables for below-ground and above-ground pools; spas; wading pools; number of showers, baths, hand basins, laundries, washing machines and sinks; dummy variables for dual-flush toilets, dishwashers and garbage-disposal units
Nauges and Reynaud	2001	Average annual water consumption per household (separate regressions for Gironde and Moselle)	AP for an annual consumption of 100 m3 (Gironde), MP (Moselle) (prices include sewage charges)	Net income; taxable income	% of households with 1 or 2 persons	Total precipitation in June, July and August; Total annual precipitation	Population density (hab/km2); % of population aged over 60 years; % of population aged less than 20 years; % of households owning at least one car; % of single housing units; % of houses with bathtubs; % of houses built before 1949; % of houses built after 1982; Variables used to test the price endogeneity: For Gironde: Number of connections/subscribers; length of the distribution network; distribution network efficiency (distributed volume/consumed volume); net loan annuities of the water utility per subscriber; ratio of industrial water use to residential water use; For Moselle: number of connections; network lenght; number of repaired leaks

Authors	Year of publication	Dependent variable - water consumption / demand	Explanatory variables				
			Price	Income	Household size	Weather	Others
Nauges and Thomas	2000	Average annual water consumption per household	MP and AP (AP chosen after passing exogeneity test)	Average income before tax; industry activity rate of growth	% of households with 1 or 2 persons	Average annual precipitation; total summer precipitation	% of metered households; Number of connections to the system; number of detected leaks; length of the distribution network; % of the population aged over 60 years; Population density; % of single housing units; % of houses with bathtub; % of households owning at least 1 car; % of houses built before 1949; % of houses built after 1982
Renwick and Green	2000	Average monthly household water consumption	MP and difference (Taylor-Nordin specification) (instrumented from lagged marginal price for each block of the rate schedule and the remaining socioeconomic exogenous variables); Dummy for block pricing	Average monthly gross household income	-	De-seasonalized average maximum daily temperature and precipitation (deviations from estimated historical hamonic means: Fourier series of sine and cosine terms of various harmonic frequencies)	Dummies for public information campaigns; and subsidies to encourage adoption of more water efficient technologies (ultra low flow toilet rebate programs and distribution of free retrofit kits); rationing programs; water use restrictions; compliance affidavit saying that water efficient devices were installed. Dummies for low or significant irrigation (expected differences in outdoor water use patterns by the agency); Lot size
Rietveld et al.	2000	Monthly water consumption	MP	Virtual Income (income of a household conditioned on the marginal price it pays for water)	X	-	Dummy variable for the case where a household has an extra water source (usually the river or a well)
Corral et al.	1999	Average monthly water consumption	MP and difference (Taylor-Nordin specification), average/weighted MP and average/weighted difference (the weights are proportion of users per block)	Virtual income (income + difference)	-	Temperature and precipitation	15 dummy variables for conservation and education programmes, billing information, water use restrictions
Dzisiak	1999	Average quarterly household water consumption	MP, AP	X	-	Net available moisture (precipitation - potential evapotranspiration from grass)	Average number of rooms per house; Dummies to diferentiate the quarterly billing periods; dummy variables for monthly and bimonthly billing periods. Dummy variable for drought periods (also interacted with price)
Höglund	1999	Quantity of metered water per house	MP and AP	X	X	-	Regional dummy
Merrified and Collinge	1999	Household water consumption	-	Per capita income	-	-	Population
Pint	1999	Household water consumption	MP and MP^2	-	-	Precipitation, temperature, lagged precipitation and lagged temperature	House size and lot size
Renzetti	1999	Total water consumption by households; Total water consumption by nonresidential customers; total wastewater drained	MP of water and price of sewage treatment for a cunsumption of 20m3/month for residential customers and 100m3/month for nonresidential customers	X (for the household equation)	-	5 variables: Number of days per year when temperature >25.ºC and >30.ºC; when precipitation is between 2 and 10mm, between 10 and 25 mm and >25mm	Price of electricity; number of households (for the household equation); value of the manufacturing sector's output and number of manufacturing firms (for the non-household equation)

Authors	Year of publication	Dependent variable - water consumption / demand	Explanatory variables				
			Price	Income	Household size	Weather	Others
Billings and Agthe	1998	Average monthly household water consumption	MP and difference (Taylor-Nordin specification) (instrumentes from a linear approximation to the total water bill)	Real income per capita	-	Average temperature and total precipitation (in deviations from the historic average)	Monthly dummies
David and Inocencio	1998	Monthly household water consumption	MP and difference (Taylor-Nordin specification)	Household income	X	-	Distance from water source; dummy variable for water source, for water quality perception variable, for home ownership and sewer connection; number of years of schooling; number of supply hours
Largo et al.	1998	Monthly household water consumption	MP	Household income	X	-	Dummy variable for quality perception variables, home ownership and use of shower; Type of sanitation system (ordered in relation to the water use)
Mattos	1998	Monthly average household water consumption	MP and difference (Taylor-Nordin specification)	Added value in the municipality (as a proxy for income)	X	Temperature and precipitation	-
Renwick and Archibald	1998	Monthly water consumption	MP and difference (Taylor-Nordin specification)	Gross monthly household income	X	Precipitation	Variable for the adoption of domestic and landscape irrigation technologies (low flow toilets, low flow showerheads; water efficient irrigation (drip and hand held) and traditional irrigation (sprinklers and hoses)) (previously estimated from technology adoption equations); Number of taps; dummy variables for lot size (to identify outdoor water consumption); dummies for specific restriction policies; regional and monthly dummy variables; home ownership (only for the technology adoption equations)
Agthe and Billings	1997	Monthly water purchased	MP and difference (Taylor-Nordin specification) (instrumented from a regression of the water bill on quantities consumed)	Average per capita income	-	Temperature and precipitation	-
Dandy et al.	1997	Annual water consumption	MP and difference (Taylor-Nordin specification)	Property value (proxy for income)	X	Summer moisture deficit (potential evapotranspiration - 0.6 precipitation)	Plot size; Number of rooms; Pool ownership; Seasonal dummy variable; Water consumption lagged one year (regressions performed with and without this variable creating static and dynamic models); Dummy variable = 1 if consumption is above the free allowance (and interaction between this dummy and all other variables, separately)
Espey et al.	1997	Price-elasticity of water demand	MP, AP, MP and difference and Shin price or price perception	X	X	Evapotranspiration, precipitation and temperature	Population density, seasonal dummy, long-run demand, lagged dependent variable, functional form (linear and log-linear) and estimation technique (OLS and other than OLS)
Malla and Gopalakrishnan	1997	Total monthly water use by multi-unit dwellings; water per unit; water per capita	MP and difference (Taylor-Nordin specification)	X	Number of residents	precipitation	Number of dwelling units in the multi-unit; Number of swimming pools

Authors	Year of publication	Dependent variable - water consumption / demand	Explanatory variables				
			Price	Income	Household size	Weather	Others
Saleth and Dinar	1997	Average monthly water consumption (for all cases, or divided by consumption barcket or divided by housing category (bungalow with and without garde, traditional house, house in the slum areas)	MP and difference (Taylor-Nordin specification) and AP	-	X	-	-
Barkatullah	1996	Quarterly household water consumption	MP and difference (Taylor-Nordin specification) (regression of observed demand on the fixed charge, 3 block prices and the remaining exogenous variables, after which predicted consumption values are used to calculate instrumented marginal prices and difference values for the main regression)	Household income and assessed value of the house	X	Temperature and lagged precipitation	Dummy variable for summer quarters; number of bedrooms; number of bathrooms/toilets; garden condition
Dziegielewski	1996	Price-elasticity of demand	MP	-	-	-	Dummies for significant estimate, IBT, log-linear equation and Eastern US; short-run elasticity, average annual demand, summer season demand, sprinkling demand
Hansen	1996	Per capita water consumption	MP (current and lagged) (divided by the number of apartments sharing a common meter if that is the case)	Disposable gross income	-	Sprinkling need index based on summer precipitation (one for each type of house: detached, row, apartment)	Energy price (current and lagged); dummy variables for detached and row houses
Andrade et al.	1995	Monthly household water consumption	MP and difference (Taylor-Nordin specification) (regression of observed demand on marginal prices for specific valus of consumption, after which predicted consumption values are used to calculate marginal prices from the rate schedule (IV))	Household income categories and also separate regressions for different household income categories	X	-	-
Hewitt and Hanemann	1995	Monthly household water consumption	MP and difference (Taylor-Nordin specification) (includes sewerage charges) (two types of instrumentation for the 2SLS and the IV models: regression of price on exogenous variables and marginal prices for specific values of consumption (2SLS); regression of observed demand on marginal prices for specific valus of consumption, after which predicted consumption values are used to calculate marginal prices from the rate schedule (IV))	Monthly income proxy calculated from the assessed value of the house	-	Potential evapotranspiration for bermuda grass minus precipitation	Number od days in the billing period; Lawn size; Number of bathrooms

Authors	Year of publication	Dependent variable - water consumption / demand	Explanatory variables				
			Price	Income	Household size	Weather	Others
Bachrach and Vaughan	1994	Household water consumption	MP and Difference (Taylor-Nordin specification) (instrumented from rate charged per cubic meter of water in 14 consumption block intervals and location dummies)	Income and the electricity bill as a wealth proxy	Number of adults in the household	-	Number of water faucets; Average number of service interruptions per month
Crane	1994	Monthly household water consumption (2 separate regressions: from water vendors and from public taps)	Unit price	Monthly household income	X	-	dummy for water source; time necessary to puchase or to collect water; distance to nearest hydrant; time to commute to work; age of head of household; years in house; tenant; house size; dummy for shared toilet; reservoir capacity; rural location dummy
Walters and Young	1994	Average monthly household water consumption	AP, MP and MP and Difference (Taylor-Nordin specification)	X	X	Average maximum summer (June, July and August) temperature and average monthly summer precipitation	Frequency of billing; Conservation education programs
Boistard	1993	Average per capita water consumption	AP for a consumption of 100m3 per year (with and without sewer charge)	-	-	-	-
Nieswiadomy and Cobb	1993	Monthly household water consumption; type of block structure (uniform, DBT or IBT) in selection model	MP, AP and price perceived (MP(AP/MP)^k) (for 1000 gallons)	Per capita monthly income	X	Temperature and precipitation for months between last spring freeze and first fall freeze	Dummy variables for public education programme, for conservation programme and for location in California; % of homes built before 1939; % of homes that are owner occupied. Additional variables for the selection mode: percustomer debt of utility; % of residential customers; % of water purchased by the utility; population served; average and maximum day usage as a % of system capacity, 1951-1980 average annual rainfall and July temperature; annual population growth rate 1970-80; total population growth rate 1980-86; average home value
Point	1993	Average consumption per capita	AP for a consumption of 150m3 per year	Fiscal potential	-	-	Square root of the ratio between nonpermant and permant habitants; área por habitante
Lyman	1992	Bimonthly household water consumption	MP, ratio of peak to off-peak MP, fixed charge (all lagged one period)	household income and assessed value of house and property	-	Temperature and precipitation (linearly and squared); number of cooling degree days and of heating degree days	Average age of household members; number of persons <10 years, between 10 and 20years, and older than 20 years of age; age of the house; number of bathrooms; dummy variables for water heat, sprinkler system, peak and off-peak period, spring and peak and srping together; price index; Past water consumption; indexes for lawn size, degree of yard shaded; size of flower garden, size of vegetable garden
Martin and Wilder	1992	Monthly household water consumption	MP and AP (instrumented from MP, income and the set of monhly dummy and interacted variables)	Household income (proxy for water using appliances ans the intensity of thier use)	-	-	Monthly dummy variables (alone and interacted with income)
Nieswiadomy	1992	Monthly household water consumption	MP, AP and price perceived	Per capita monthly income	X	Temperature and precipitation	Dummy variables for the existence of a water conservation program and for na educational program; % of homes built before 1939; % of homes that are owner occupied

Authors	Year of publication	Dependent variable - water consumption / demand	Explanatory variables				
			Price	Income	Household size	Weather	Others
Renzetti	1992	Household water consumption; industrial water consumption	other (instrumental variable for price)	Household available income	X	Temperature and precipitation	Added-value by manufactures in the region and % of self-supplied water (for the industrial demand regression)
Stevens et al.	1992	Average household water consumption	AP (including sewer charges) (instrumented from the minimum service charge and the remaining exogenous variables)	Per capita income (proxy for water using appliances)	-	Temperature and precipitation	Billing frequency; population density (proxy for urban/rural differences such as lawns and gardens); dummy variable for location; dummy variables for type of rate structured (also interacted with the remaining exogenous variables - 3 different regressions in practice)
Woo	1992	Per capita water consumption	AP; Instruments used for Hausman test: exogenous variables, first and last residential block rate, average of block rates, difference variable at the last block, number of blocks, commercial rate	Per capita income	-	Precipitation-evaporation; temperature	Monthly hours of supply; monthly dummy variables
Griffin and Chang	1991	Per capita residential and commercial water consumption	AP	Per capita income	-	Number of days without significant precipitation (≥ 0.25 inches); Average annual precipitation	% of population from hispanic origin
Nieswiadomy and Molina	1991	Monthly household water consumption	AP/MP and MP to test the k paramenter in price perceived (MP(AP/MP)^k). [AP is from the previous month] (AP includes all charges for water and sewage) (MP instrumented from lawn size, weather, income house size, flat fee and 3 block prices during DBT and 2 block prices during IBT)	Income proxy based on the value of the house	-	Weather variable (Potential evapotranspiration for Bermuda grass - Precipitation); Water consumption lagged one month	Lawn size
Rizaiza	1991	Annual household water usage	AP	Average annual family income	X	Temperature	Number of school years of the head of household; dummy variables for houses with gardens and for houses with sewers (instead of septic tanks); dummy variables for water supply by tanker (instead of public water network); city dummy variables
Schneider and Whitlatch	1991	Average annual consumption per account	MP (including sewer rates)	Per capita income	X	Summer precipitation (May-August)	Housing composition (single-unit dwellings/total dwellings)

Authors	Year of publication	Dependent variable - water consumption / demand	Explanatory variables				
			Price	Income	Household size	Weather	Others
Billings	1990	Monthly household water consumption	AP	Monthly household income	X	Average temperature, high temperature (degrees exceeding 58ºF), monthly summer precipitation, % of annual daylight hours during month	Lagged water consumption, ratio of current customer to customers in January 1974; % of heads of household aged between 55 and 64 and aged 65 and over
Griffin and Chang	1990	Per capita and per day residential and commercial water consumption	AP (including sewer charges) paid by na average 2.84 person household and MP-AP; rate change dummy variable (=1 if rate changed in the current or in the previous 2 months) (AP is preferred)	Annual personal income per capita	-	Number of days without significant precipitation (≥ 0.25 inches) * month's average temperature	% of population with spanish origin
Miaou	1990	Annual per capita water produced	AP	Per capita income	Number of households per unit of population	Precipitation and temperature (year and summer averages)	-
Mu et al.	1990	Water used per capita per day ("water carried home") [a discrete choice model for the water source is also estimated]	-	X	-	-	Time it takes to collect water from different sources; Proportion of women in a household; perception of the taste of water; numer of years of formal education of household members; dummy variable for the type of water access (water kyosk; water vendor; wells)
Billings and Day	1989	Monthly household water consumption	MP and difference (Taylor-Nordin specification) and AP	X	X	Temperature, precipitation	Weighted index of articles appearing in the leading area newspaper related to water problems; % of homes occupied by owner; % of people aged 55-64; % of people aged 65 or older; % of new households; growth in water connections
Moncur	1989	Average daily water pumpage	X	X	-	Rainfall, lagged rainfall	Dummy for water restrictions
Nieswiadomy and Molina	1989	Monthly household water consumption	MP and difference (Taylor-Nordin specification) (includes sewerage charges); MP and AP (MP and difference instrumented from lawn size, weather, income house size, flat fee and 3 block prices during DBT and 2 block prices during IBT; alternatively (IV model); MP and difference are calculated from a regression of water demanded on actual marginal prices for different levels of consumption (2SLS model))	Monthly income proxy calculated from the assessed value of the house	-	Potential evapotranspiration for bermuda grass minus precipitation	Lawn size; house size

Authors	Year of publication	Dependent variable - water consumption / demand	Explanatory variables				
			Price	Income	Household size	Weather	Others
Weber	1989	Monthly household water consumption	MP	Monthly household income	-	Average monthly precipitation and mean maximum temperature; actual precipitation and temperature; deviation of precipitation and temperature from historical values; moving averages of precipitation and temperature	Seasonal index, monthly dummy variables, time trend
Wilson	1989	Average summer sprinkling water use	MP	Market value of the dwelling unit (proxy for income)	-	Moisture deficit (summer [June August] evapotranspiration minus effective [0.6] precipitation)	-
Nieswiadomy and Molina	1988	Monthly household water consumption	MP and difference (Taylor-Nordin specification) (includes sewerage charges) (two types of instrumentation: regression of price on exogenous variables and marginal prices for specific values of consumption (2SLS); regression of observed demand on marginal prices for specific valus of consumption, after which predicted consumption values are used to calculate marginal prices from the rate schedule (IV))	Monthly income proxy calculated from the assessed value of the house	-	Potential evapotranspiration for bermuda grass minus precipitation	House age; lawn size
Palencia	1988	Average monthly household water consumption	MP and difference (Taylor-Nordin specification)	Average household income	X	-	Total population (index for urbanization)
Thomas and Syme	1988	Average annual household water consumption (with and without adjustment to account for boreholes)	MP and difference (Taylor-Nordin specification)	X	X	Precipitation	Hours per year of restrictions on water supply; % of households with private groundwater borehole or well
Agthe and Billings	1987	Monthly household water consumption (for 4 different income groups)	MP and difference (Taylor-Nordin specification); dummy variables for simultaneous change in MP and difference and for changes only in difference.	Personal income per household	X	Evapotranspiration minus precipitation	Dummy for swimming pools, frontyard and backyard vegetation
Billings	1987	Monthly household water consumption	MP and difference (Taylor-Nordin specification) (instrumentes from a linear approximation to the total water bill)	Monthly household income	X	Average temperature, high temperature (degrees exceeding 58ºF), monthly summer precipitation (for the months when temperature exceeds 58ºF)	Estimate of water-related publicity; % of homeowners, % of heads of household aged between 55 and 64 and aged 65 and over; new households (% of households in home 1 year or less); ratio of current customer to customers in January 1974
Frerichs et al.	1987	Annual water demand per connection	AP and MP and Difference (Taylor-Nordin specification)	X	X	-	Dummy variable for large cities; % of people <18 years of age

Authors	Year of publication	Dependent variable - water consumption / demand	Explanatory variables				
			Price	Income	Household size	Weather	Others
Moncur	1987	Household water consumption	MP	Income per household member	X	precipitation	Dummy (water restrictions program)
Schefter	1987	Average quantity of water demanded per household per year	MP and difference (Taylor-Nordin specification)	X	-	-	-
Agthe et al.	1986	Monthly household water consumption	MP and difference (Taylor-Nordin specification) instrumented from water consumption, dummy variables for price changes in water and sewer tariffs	Personal household income	-	Evapotranspiration minus precipitation	Past water consumption; time trend
Chicoine and Ramamurthy	1986	Monthly household water consumption	MP, AP-MP (decomposed price variable)	Virtual income (income - difference variable)	X	-	Monthly dummy variables; Number of bathrooms
Chicoine et al.	1986	Household water consumption	MP and difference (Taylor-Nordin specification), AP (all instrumented from water consumption, minimum bill, average marginal price in the rate structure and average changge in marginal price from moving from one block to the next) and others	Household income	X	-	Number of bathrooms
Deller et al.	1986	Monthly household water consumption	MP and difference (Taylor-Nordin specification)	Monthly household income	X	-	Number of bathrooms
Martin and Thomas	1986	Average daily per capita water consumption	MP	-	-	-	-
Williams and Suh	1986	Annual water demanded by customer class	MP, AP and other (typical monthly bill for consumptions of 3750, 7500 and 7500 gallons)	X (only for residential equation)	-	Summer temperature (for residential and commercial equations) and summer precipitation (only for residential equation)	Added values in manufacturing (only for industrial equation); receipts in establishments of selected services (only for commercial equation); Number of customers in each class; population density (only for residential equation)
Al-Qunaibet and Johnston	1985	Per capita monthly water consumption	AP	Per capita income	-	Relative humidity (estimated from mean temperature, mean minutes of sunshine, mean wind speed)	-
Cochran and Cotton	1985	Annual water production per capita	AP	Per capita income	Number of households per unit of population	Precipitation and temperature	-

Authors	Year of publication	Dependent variable - water consumption / demand	Explanatory variables				
			Price	Income	Household size	Weather	Others
Schefter and David	1985	Household water consumption	MP and difference (Taylor-Nordin specification), average/weighted MP and average/weighted difference (the weights are proportion of users per block)	Average household income	-	-	-
Jones and Morris	1984	Water use of single-family residences	MP and difference (Taylor-Nordin specification) (instrumental variables developed from average water use b rate class during summer and winter) and AP (instrumental variable: AP was estimated from a regression of the logarithm of observed average price on exact rate information such as the fixed component, initial variable charge and the difference in charges between subsequent and adjacent blocks)	Family income (instrumental variable regressed from property value of the residence; construction date of the residence; educational level of the head of the household; job of the head of the household; numer of cars registered at the address)	X	-	-
Young et al.	1983	Quarterly household water consumption by low, medium and high consumption groups	-	Assessed value of the house (proxy for income)	X	-	Annual time trend; seasonal dummies; dummy for the use of water conservation devices; dummy for the use of dishwashing machines
Billings	1982	Monthly water consumption of the average household	MP and difference (Taylor-Nordin specification) (instrumentes from a linear approximation to the total water bill)	X	-	Evapotranspiration minus precipitation	Implicit sewer charge during winter months
Hanke and de Maré	1982	Water consumption per house	MP	X	X (2 separate variables: number of adults per house and number of children per house)	precipitation	Dummy variable for the age of the house (1 for houses built in the period 1968-69, o otherwise, i.e., built in the period 1936-1946)
Howe	1982	Daily household water consumption	MP and difference (Taylor-Nordin specification)	Market value of the dwelling unit (proxy for income)	-	Moisture deficit (calculated from outdoor irrigable area, potential evapotranspiration rate and averge summer precipitation rate)	-
Ford and Ziegler	1981	Household water consumption	MP and AP	Household income, house value and financial resources	X	Temperature and precipitation	Household average age, number of children; number of water using appliances; of plumbing fixtures; of faucets; size of swimming pool; lawn area; garden area; perceived water quality; town size; age of water using appliances
Foster and Beattie	1981	Average quantity of water demanded per household	MP and difference (Taylor-Nordin specification) compared to the AP specification of Foster and Beattie, 1979.	Median household income	Average number of persons per service meter (may include more than one household)	Precipitation during the growing season (months where the temperature is at least 45ºF in the North and 60ºF in the South)	-

Authors	Year of publication	Dependent variable - water consumption / demand	Explanatory variables				
			Price	Income	Household size	Weather	Others
Agthe and Billings	1980	Monthly water consumption	MP and difference	X	-	Evapotranspiration minus precipitation	-
Ben-zvi	1980	Non-industrial use per customer (lowest monthly use for winter demand regression; average use in April-September - average use, for summer water demand)	MP (nonindustrial) plus treatment cost; average cost of sefl-supplied water (industrial)	Value of sales	-	-	-
Billings and Agthe	1980	Average monthly household water consumption	MP and difference (Taylor-Nordin specification)	Real income per capita	-	Evapotranspiration minus precipitation	Implicit sewer charge during winter months
Carver and Boland	1980	Water consumption per connection per day (different models for nonseasonal [November-April] and seasonal consumption [May-October minus the average of November-February])	MP	Real household income	X	Moisture deficit (evapotranspiration minus efective precipitation) (only for seasonal model)	Dummy variable for the imposition of a excess use charge; Past water consumption (lagged 1 year); employee per connection; household-specific and time-specific dummy variables
Cassuto and Ryan	1979	Monthly household water consumption	MP (price of the first block) (current and lagged)	Real mean income per household	X	Temperature (valued 0 if <65ºF [18.3ºC]) and precipitation	Lot size; weekend days per month; weighted average elevation of census tract; energy price index; time trend; days per month; dummy variable for month
Colander and Haltiwanger	1979	Water produced/pumped per active account	AP	-	-	precipitation	-
Danielson	1979	Separate winter/indoor and summer/outdoor water consumption	MP (price of the first block)	Value of the house (proxy for income)	X	Temperature and precipitation	-
Foster and Beattie	1979	Quantity of water demanded per meter	AP	Median household income	Average number of persons per service meter (may include more than one household)	Precipitation during the growing season (months where the temperature is at least 45ºF in the North and 60ºF in the South)	City/region dummy variables (USA divided in 6 regions); Size-of-city dummy variables
Camp	1978	Monthly household water consumption	MP	Market value of the residence (proxy for income)	X	Average maximum temperature and total annual precipitation	Age of head of household; irrigable lawn area of residence; number of bathrooms, clothes washers and dishwashers. Existence of a swimming pool; Race; Educational index
Gibbs	1978	Quarterly household water consumption	MP and AP; dummy variable for zero-price cases	Annual household income	X	-	Seasonal dummy variables; % of homes with hot-water heat

Authors	Year of publication	Dependent variable - water consumption / demand	Explanatory variables				
			Price	Income	Household size	Weather	Others
Katzman	1977	Average monthly household consumption	Dummy for price increase	Income dummies (high income, middle incom, poor)	Number of household members over and under 16 years of age	precipitation	Dummy for urban residence; dummy for alternative sources of water; time trend
Clark	1976	Per capita water consumption	MP	-	-	-	-
Grunewald et al.	1976	Quantity of water used per household	AP	Mean household income	X	Potential evaporation (June-September)	Value of the dwelling unit
Morgan and Smolen	1976	Municipal water use per capita per day (4 different models/samples: total sample or 12 months; wet season (November through March, revealing indoor water use); dry season (April through October); Sprinkling demand (total sample with the minimum consumption form the wet season subtracted to reveal summer sprinkling demand)	AP (time-invariant over the 12 months of the study)	Median family income (time-invariant over the 12 months of the study)	-	3 alternative climatic specifications (temperature and precipitation; potential evapotranspiration - precipitation; monthly binary seasonal variables) (the use of temperature and precipitation yields the best results)	-
Andrews and Gibbs	1975	Household water consumption (different regresssions for MP and AP)	MP and AP (in the MP model a dummy variable is introduced to differentiate zero and non-zero MP)	Annual household income	X	-	% of households with hot heater; seasonal quarterly dummy variables (February-April, May-July, August-October and November-January)
Attanasi et al.	1975	Per capita water consumption	AP	X	-	-	-
Batchelor	1975	Annual household water consumption	-	Net annual value of the property	X	-	Age of the house; dummy variables for the existence of toilets and to distinguish apartments from houses with gardens; number and type of the following water using appliances: washing machines, cars, dish-washers, showers and garden sprinklers
Darr et al.	1975	Per capita water consumption (3 separate regressions: including and excluding gardening and gardening only)	-	Gross monthly household income	X	-	Cultural origin; education and age of the head of household; number of rooms per household; regional dummies
Hogarty and MacKay	1975	Per capita water consumption	MP	-	-	-	-
Morgan	1974	2 regressions: Quantity of water consumed by each household; total water consumed in each billing period	Dummy variable for an increase in price for the last 6 billing periods	-	-	precipitation	Dummy variables for the individual households (not included in the 2nd regression); Seasonal dummy variables for each bimonthly period within a year; Linear time trend increasing one unit each bimonthly period

Authors	Year of publication	Dependent variable - water consumption / demand	Explanatory variables				
			Price	Income	Household size	Weather	Others
Grima	1973	Average daily water use per dwelling (3 separate regressions: year, summer, winter)	Variable price; Fixed bill	Assessed value of the residence	X	-	-
Morgan	1973	Water consumption (for November-December; for January-February; for the 4 months combined)	-	-	X	-	Assessed value of property
Young	1973	Water produced/pumped per active account	AP	-	-	precipitation	-
Wong	1972	Per capita water consumption	AP	Average household income	-	Average summer temperature (only for the time-series regression)	-
Hanke and Davis	1971	Water consumption per user (separate regressions for residential indoor, residential sprinkling, commercial/ industrial, public/ innacounted; separate regressions for winter and summer)	MP (second-block rates)	-	-	-	-
Hanke	1970	Sprinkling water consumption; Indoor water consumption	Dummy variable for the introduction of metering and a single volumetric charge	-	-	"Ideal sprinkling consumption" (based on "average irrigable area per dwelling unit, mean monthly temperature, monthly percent of daylight hours, effective precipitation, and na empirical monthly crop coefficeint for grass"	Interaction between the ideal sprinkling consumption and the dummy variable
Turnovsky	1969	Per capita water consumption	AP	-	-	-	Index of per capita housing space (rooms/occupants) and % population <18 years (both only for residential regression); index of per capita industrial production (only for industrial regression); Variance of water supply
Meroz	1968	Average daily per capita water consumption	AP; dummy for volumetric charge	Per capita income	-	Average daily maximum temperature; precipitation-temperature index	% of population served
Conley	1967	Per capita consumption	MP (per 1000 gallons and per 10000 gallons) and AP (per 1000 gallons)	-	-	-	-
Howe and Linaweaver	1967	Water consumption per dwelling unit (Separate winter/indoor and summer/outdoor/sprinkling)	MP (including sewer charges); Marginal summer charge (for sprinkling regression only)	Market value of the dwelling unit (proxy for income)	X	For sprinkling regression only: summer potential evapotranspiration; Maximum day potential evapotranspiration; summer precipitation	Average water pressure; age of the house; for sprinkling regression: irrigable area per dwelling unit; maximum day sprinkling demand
Bain et al.	1966	Per capita consumption	AP	-	-	-	-
Flack	1965	Per capita consumption	AP	-	-	-	-

Authors	Year of publication	Dependent variable - water consumption / demand	Explanatory variables				
			Price	Income	Household size	Weather	Others
Gardner and Schick	1964	Daily per capita water consumption	AP	Per capita income	-	Temperature and precipitation	Per capita lot area; % of homes with complete plumbing units
Gottlieb	1963	Per capita consumption	AP	Average household income	-	-	-
Headley	1963	Average daily per capita water consumption	-	Household income	-	-	-
Fourt	1958	Per capita consumption	AP	Per capita income	X	Number of days of precipitation in June, July and August	-
Seidel and Baumann	1957	Water production	AP	-	-	-	-
Larson and Hudson	1951	Daily per capita residential water used	-	Net family income	-	-	-
Metcalf	1926	Municipal water use	AP	-	-	-	-

Authors	Year of publication	Type of tariff structure	Price-elasticity	Income-elasticity	Other elasticities
Bartczak et al.	2009	Uniform price	-0.23 to -0.22	0.12 to 0.16	Household size: -0.35 to -0.32
Diakité et al.	2009	3-block IBT	-0.816	0.146	-
Garcia-Valiñas et al.	2009	Two-part tariffs	-0.16	-	-
Olmstead	2009	IBT (2-blocks and 4-blocks)	Unconditional elasticity from DCC model: -0.609; elasticities conditional on the choice of block: -0.292 (IV model); -0.641(DCC model)	Unconditional elasticity from DCC model: 0.1865; elasticities conditional to the choice of block: 0.683 (IV model); 0.1959 (DCC model)	-
Ruijs	2009	5-block IBT (with fixed charge for 1st block)	-0.20 (short-run); -0.28 (long-run)	0.19 (short-run); 0.28 (long-run)	-
Schleich	2009	Single price (average price)	-0.22	0.21	-
Schleich and Hillenbrand	2009	Uniform price	-0.252 to -0.23	0.355	Household size: -0.436 (regarding per capita consumption); Population age: 0.603; share of households with wells: -0.014
Arbués-Gracia et al.	2008	Uniform price	-0.129 to -0.033	0.811 to 1.286	Percentage effect of the temperature dummy variable (-5.361 to -1.779); percentage effect of central heating (-36.014 to -31.470)
Azomahou	2008	Two-part tariff	-0.354 to -0.180	0.036 to 0.096	0.264 to 0.286 (spatially lagged dependent variable)

Authors	Year of publication	Type of tariff structure	Price-elasticity	Income-elasticity	Other elasticities
Basani et al.	2008	Uniform price	-0.52 to -0.41	0.68 (expenditure)	Household size: 0.056 to 0.058
Bell and Griffin	2008	Block-tariffs	-0.127	-	-
Cheesman et al.	2008	Uniform price	-0.059 (private connections) (-0.081 for households who knew the water price); -0.53 (private connections and wells); -0.44 (well water)	0.141	Household size: 0.507
Frondel and Messner	2008	-	-0.485 (price conscious households); -0.300 (others)	0.128 (price conscious households); 0.306 (others)	Household size: 0.303 (price conscious households); 0.206 (others)
Kenney et al.	2008	Fixed charge + uniform price or IBT	-0.6 (-0.75 to -0.34). During restrictions: -0.37 (-0.24 to -0.46)	-	Temperature: 0.02; precipitation: -0.04
Miyawaki et al.	2008	IBT	-1.14 to 0.18	-0.15 to 0.18	Household size: 0.17 to 0.23; Number of rooms: 0.009 to 0.14; Floor space: 0.035 to 0.079; Lagged consumption: -0.15
Nataraj and Hanemann	2008	Fixed charge + IBT (2 blocks until 1994, 3 blocks afterwards)	-	-	-

Authors	Year of publication	Type of tariff structure	Price-elasticity	Income-elasticity	Other elasticities
Nauges and Berg	2008	5-block IBT plus fixed charge	-0.15 (piped water); -0.37 (piped water and other sources); -0.006 (other sources)	0.138 (piped water)	-
Reynaud	2008	-	-0.15 (peak period); -0.12 (off-peak period)	-	-
Ruijs et al.	2008	5-block IBT (with fixed charge for 1st block)	Between −0.45 and −0.50	Between 0.39 and 0.42	-
Statzu and Strazzera	2008	IBT; higher tariff for nonresidents; lower tariff for low income households	-0.161 to -0.139	0.105 to 0.199	Household size: 1.063 to 1.119; % home owners: -0.525 to -0.463; Altitude: -0.027 to -0.024
Strong and Smith	2008	Uniform price and IBT	-0.41 to -0.125	0.62	-
Xayavong et al.	2008	IBT	-1.15 to -1.06 (indoor: 0.94 to -0.70; outdoor: -1.45 to -1.30)	0.5 to 0.6	-
Babel et al.	2007	Block tariffs after minimum free allowance (10m3/month)	-0.167	-	Number of connections: 1.055; Ratio of the population to the number of university students: 0.5; precipitation: -0.21
Dahan and Nisan	2007	3-block IBT	-0.18	-	-
Fullerton et al.	2007	IBT	-1.04	-	-
Grafton and Kompas	2007	Uniform price	-0.352086	-	Temperature: 0.221793; water restrictions: 0.107878
Grafton and Ward	2007	Uniform price	-0.17	-	-

Authors	Year of publication	Type of tariff structure	Price-elasticity	Income-elasticity	Other elasticities
Mansur and Olmstead	2007	IBT and uniform price	Overall indoor -0.07; overall outdoor - 0.68; arid season indoor 0.06, arid season outdoor -0.74; wet season indoor -0.10; wet season outdoor -1.18 ("households with the largest incomes and lot sizes have the least price elastic outdoor demand" (Grafton and Ward, 2006))	-	-
Martínez-Espiñeira	2007	Fixed quota plus 3-blocks increasing tariff + sewage collection fee + treatment fee + water infrastructure fee (since 1994) + extra fee (1993-1997, "charged for the company's finances to recover from the impact of the drought.")	Short-run: -0.159 to -0.073; Long-run: -0.514 to -0.405	-	-
Martins and Fortunato	2007	Fixed charges (connection + sewerage charge) + IBT	-0.558	-	-
Musolesi and Nosvelli	2007	IBT	-0.47 (long-run); -0.27 (short-run)	0.181	Household size: 0.324; % of population > 65 years of age: -0.09
Nauges and Strand	2007	-	Non-tap water demand elasticities with respect to total water cost (defined as the sum of water price and hauling cost): -0.655 / -0.579 (private tap); -0.657 / -0.542 (public tap); -0.591 (public well); -0.418 / -0.088 (trucks).	0.231-0.299	Household size: -0.693 to -0.350

Authors	Year of publication	Type of tariff structure	Price-elasticity	Income-elasticity	Other elasticities
Olmstead et al.	2007	IBT and uniform price	-0.33 (-0.5893 para a amostra só com IBT e -0.3258 para a amostra só com preços uniformes) (unconditional elasticity vs. elasticity conditional to the consumption block)	0.13 (-0.1786 para a amostra só com IBT e 0.0432 para a amostra só com preços uniformes) (unconditional elasticity vs. elasticity conditional to the consumption block)	-
Yoo	2007	Uniform price	-0.759	0.109	Household size: 0.443
Arbués and Villanua	2006	IBT + fixed charge	ranged between -0.081 and –0.029	0.7919	Household size elasticity of the demand: 0.479
Fullerton et al.	2006	-	-	-	-
Garcia-Valiñas	2006	Fixed charge + IBT (3 blocks for households, 2 blocks for firms)	-	-	-
Gaudin	2006	DBT, IBT, uniform price	-0.37 (-0.36 for areas that do not include the information about the MP and -0.51 for areas that do)	0.3	-

Authors	Year of publication	Type of tariff structure	Price-elasticity	Income-elasticity	Other elasticities
Hoffmann et al.	2006	Two-part tariff	Logarithmic model: -0.507 (-0.455 for owner-occupier households and -0.391 for renter households); Linear model: -0.588 (-0.607 for owner-occupier households and -0.399 for renter households)	Logarithmic model: 0.235 (0.298 for owner occupier households and 0.191 for renter households); Linear model: 0.239 (0.234 for owner-occupier households and 0.276 for renter households)	Household size: 0.169 to 0.414; Rainy days: -0.273 to -0.168; Warm days: 0.006 to 0.020; Lagged quarterly demand: -1.579 to -0.658
Jansen and Schulz	2006	3 to 6 block IBT	0.99 to -0.23	-	temperature: 0.318; household size: 0.565
Kostas and Chrysostomos	2006	-	-0.1	0.72	-
Larson et al.	2006	-	-	-	-
Mazzanti and Montini	2006	IBT	-1.33 to -0.99	0.40 to 0.71	-
Carter and Milon	2005	Fixed charge + uniform price or IBT	-3.054 (MP; knows the price; long-run) to 0.061 (AP, does not know the price, short-run)	0 to 0.255	-
Dalmas and Reynaud	2005	Uniform price	-0.41 to -0.28	0.26 to 0.41	Household size: -0.74
Garcia-Valiñas	2005	Fixed charge + IBT (3 blocks for households, 2 blocks for firms)	-0.55 to -0.46 (residential); -0.75 to -0.69 (industrial/ commercial)	0.58	-
Garcia-Valiñas	2005	Fixed charge + 4-block IBT for households and two-part tariffs for commercial/industrial	-0.11 to -0.09 (residential); -0.13 to -0.12 (industrial/ commercial)	0.39	-

Authors	Year of publication	Type of tariff structure	Price-elasticity	Income-elasticity	Other elasticities
García-Valiñas	2005	Two-part tariff	-0.04 (residential); -0.11 (commercial/ industrial)	0.27	-
Gaudin	2005	DBT, IBT, uniform price	-0.37 (-0.28 for areas that do not include the information about the MP and -0.51 for areas that do)	0.30	-
Hanemann and Nauges	2005	Uniform price	–0.47 to –0.29 in the high season (June-October); –0.19 to 0 in the low season (November-May)	-0.008 to 0.257	Temperature: 0.006 to 0.035; precipitation: -0.446 to -0.042
Martins and Fortunato	2005	IBT	-	-	-
Reynaud and Thomas	2005	Two-part tariff	-0.15 to -0.06	-0.17 to -0.11 (not significantly different from 0)	Precipitation: -0.09

Authors	Year of publication	Type of tariff structure	Price-elasticity	Income-elasticity	Other elasticities
Reynaud et al.	2005	Flat rate, uniform price, DBT, IBT	0.02 (flat rates), -0.11 (constant unit rates), -0.25 (increasing block rates), -0.10 (decreasing block rates)	-	-
Strand and Walker	2005	IBT	-0.3 (for tap water demand) and -0.1 for non-tap water demand (-0.4 to -0.3 if all hauling costs are included)	0.02 (tap water); 0.04 to 0.08 (nontap water)	Household size: 0.06 (nontap); children (tap): 0.5 to 0.7; adults (tap): 0.8
Arbués et al.	2004	Fixed charge + IBT	-0.058 to –0.029	0.074 to 0.208	Household size: 0.734 to 0.868
Fullerton and Elías	2004	-	-	-	-
Garcia and Reynaud	2004	Fixed charge and volumetric charge	-0.2542	0.0271 (not significantly different from 0)	-

Authors	Year of publication	Type of tariff structure	Price-elasticity	Income-elasticity	Other elasticities
Martínez-Espiñeira and Nauges	2004	Fixed quota + increasing 3-block rate	-0.13 to -0.07	0.07 to 0.13	-
Mylopoulos et al.	2004	IBT (fixed charge for the first block rate) (3 blocks in the beginning of the study period, later increasing to 6)	Marginal price-elasticity of demand is found to be an inverted U-shaped function of water consumption (between -0.721 to -0.113 for MP and between -0.923 and -0.532 for AP); higher price elasticity for intermediate consumptions; lower elasticity for lower and higher consumptions	0.127	Precipitation: -0.104; dummy for water authority employee: -0.193
Taylor et al.	2004	Flat rates, uniform price and fixed charges combined with block tariffs (IBT or DBT)	-0.297	0.382	Temperature: 0.478; Summer months: 0.364
Ayadi et al.	2003	IBT	-0.48 to -0.1	-	-
Dalhuisen et al.	2003	-	-0.35 (median of studies surveyed) -0.41 (average of studies surveyed)	0.24 (median of studies surveyed) 0.43 (average of studies surveyed)	-
Fullerton and Nava	2003	-	-	-	-

Authors	Year of publication	Type of tariff structure	Price-elasticity	Income-elasticity	Other elasticities
Garcia and Thomas	2003	Fixed charge and uniform price	-0.347	-	-
Krause et al.	2003	Uniform price	-	-	-
Martínez-Espiñeira	2003	IBT (half the sample has a minimum of consumption with fixed price) (3 blocks)	-0.47 to -0.37	-	-
Nauges and Thomas	2003	Two-part tariff	Short-run: -0.26; Long run: -0.4	0.51	-
Piper	2003	-	-0.32	0.12	-
Acharya and Barbier	2002	Uniform price	-0.073 (collection and purchase); -0.067 (purchase only)	-	-
Agthe and Billings	2002	Uniform price	-0.45 (winter); -0.73 (summer)	-	-
Hajispyrou et al.	2002	Fixed charge + IBT (3 to 7 blocks); Some cases have null 1-st block prices	-0.79 to -0.39	0.22 to 0.48	-
Ipe and Bhagwat	2002	-	-0.002	0.0002	-

Authors	Year of publication	Type of tariff structure	Price-elasticity	Income-elasticity	Other elasticities
Martínez-Espiñeira	2002	Fixed charge + uniform price or Block tariff; Free allowances	-0.17 to -0.12 (overall water demand) (up to 0.41 for different specifications)	-	-
Nauges and Blundell	2002	3-block IBT plus fixed charge	-0.36 (nonparametric model); -0.21 (OLS); -0.45 (2SLS); -0.68 (ML1); -0.33(ML2) [for ML2 the following price-elasticities are reported for the sucessive income quartiles: -0.46; -0.37; -0.29]	0.70 (nonparametric model); 0.09 (OLS; 2SLS); 0.11 (ML)	-
Pashardes and Hajispyrou	2002	Block tariffs	-0.6	0.3	-
Gaudin et al.	2001	Block tariffs	-0.47 to -0.19	0.08 to 0.28	-
Gunatilake et al.	2001	IBT (free allowance for the first 10m3)	-0.34	0.08	Difference: 0.35; household size: 0.38
Higgs and Worthington	2001	Flat rate changed to fixed charge + 2-block IBT	-	-	-
Nauges and Reynaud	2001	Two-part tariff	-0.22 to -0.08	0.01	% of recent hoouses (built after 1982): -0.12 and -0.09; % of population aged less than 20 years: 0.28; % of detached houses: -0.44 to 0; % of houses with 2 or more cars: 0.37; % of houses with bathtubs: 0.59; summer precipitation: -0.08

Authors	Year of publication	Type of tariff structure	Price-elasticity	Income-elasticity	Other elasticities
Nauges and Thomas	2000	Two-part tariff	-0.22	0.09	% of population over 60: -0.22; % of single houses: -0.436; % of houses with bathtub: 0.589; % of recent houses (built after 1982): -0.119; industry activity rate of growth: 6.219
Renwick and Green	2000	Uniform price and IBT	-0.16 (overall); -0.20 (summer months)	0.25	Lot size: 0.27; temperature: 0.46; precipitation: not significantly different from zero
Rietveld et al.	2000	IBT	-1.17	0.05	-
Corral et al.	1999	Flat rates, uniform price, DBT and IBT	-0.17 to 0 (all year) and -0.30 (dry months in drought periods) to 0.14 (dry months in normal periods)	0.25 (overall); 0.545 (drought periods)	Temperature: 0.76; Precipitation: -0.016
Dzisiak	1999	Two-part tariffs (uniform price + service charge) and Multi-part tariffs (Service charge + DBT or IBT)	-0.26 (total); -0.18 (indoor); -0.34 (outdoor)	0.35 (total); 0.28 (indoor); 0.40 (outdoor)	-
Höglund	1999	Service availability charge plus uniform price or DBT	-0.122 to -0.082 (MP) and -0.264 to -0.204 (AP)	0.066 to 0.130	-
Merrifed and Collinge	1999	Fixed charge + IBT	-	0.2 to 0.46	-
Pint	1999	Uniform price and IBT	-0.47 to -0.04 (summer) and -1.24 to -0.07 (winter)	-	-
Renzetti	1999	Flat-rates; constant rates and DBT	-0.124 (residential); -0.593 (nonresidential); -0.033 (sewage)	0.596 (water supply); -0.251 (sewage treatment)	-

Authors	Year of publication	Type of tariff structure	Price-elasticity	Income-elasticity	Other elasticities
Billings and Agthe	1998	Fixed charge plus IBT	-	-	-
David and Inocencio	1998	IBT for connected households	-0.5 (-2.1 for vended water)	0.173 (0.254 for vended water)	Household size: 0.351 (0.411 for vended water)
Largo et al.	1998	IBT for connected households	-0.72	0.15	Household size: 0.866
Mattos	1998	Fixed charge with free allowances + IBT	-0.25 to -0.19	-	-
Renwick and Archibald	1998	Uniform price (until May 1989) and IBT	-0.33 (total sample); -0.53 (low income) to -0.11 (high income)	0.36	-
Agthe and Billings	1997	IBT	-0.57 (high-income) to -0.39 (middle-income); -0.51 (low-income)	-	-
Dandy et al.	1997	Two-part tariff with free allowances (fixed charge calculated as a percentage of the improved value of the property; the free allowance was obtained dividing the fixed charge by the unit price) (1991-92 introduced a fixed free allowance)	-0.86 (long-run, summer) to -0.12 (short-run, winter)	0.14 (short-run, dynamic model) to 0.49 (long-run, summer, dynamic model)	Household size: 0.04 (short-run, dynamic model) to 0.42 (long-run, winter, dynamic model)
Espey et al.	1997	Uniform price, IBT and DBT	Mean price-elasticity: 0.51 (short-run median: -0.38; long-run median: -0.64); "90% of all estimates between 0 and -0.75" (Olmstead et al. 2007)	-	-
Malla and Gopalakrishnan	1997	IBT	-0.49 to -0.162	0 to 1.370	Precipitation: -0.118 to 0.016; household size: 1.011 to 1.036

Authors	Year of publication	Type of tariff structure	Price-elasticity	Income-elasticity	Other elasticities
Saleth and Dinar	1997	Fixed charge + 3-block IBT, after an initial free allowance	0.213 (AP) and -0.580 (MP)	-	Household size: 0.476
Barkatullah	1996	Two-part tariff (for the two last quarters) of multipart-increasing tariff (fixed charge + IBT)	-0.21	0.07	Difference: -0.03; Temperature: 0.04; precipitation: -0.13; Household size: 0.17
Dziegielewski	1996	Block tariffs	-0.44 to -0.05	-	-
Hansen	1996	Two-part tariff	-0.1 to -0.003	-	Energy cross-price elasticity: -0.22 to -0.21
Andrade et al.	1995	Fixed charge with free allowances + IBT	-0.24 (-0.625 [low income]; -0.165 [average income]; -0.216 [high income])	0.019	Difference: -0,796 to 0.506; Household size: 0.043
Hewitt and Hanemann	1995	2-block IBT	-1.63 to -1.57	0.15	-

Authors	Year of publication	Type of tariff structure	Price-elasticity	Income-elasticity	Other elasticities
Bachrach and Vaughan	1994	Fixed charge with free allowances + IBT	-0.43 to -0.03	0.02	Difference: -0.09 to 0.03
Crane	1994	-	-0.48 (water vendors); -0.60 (public taps)	0.03 to 0.12	Household size: 0.06 to 0.08
Walters and Young	1994	Flat rates, uniform price and fixed charges combined with block tariffs (IBT or DBT)	-0.46 to -0.34 (metered); -0.76 to -0.72 (nonmetered)	-	-
Boistard	1993	-	-0.33 to -0.11	-	-
Nieswiadomy and Cobb	1993	Uniform price, IBT and DBT	-0.29 for DBT to -0.27 for IBT (MP), -0.64 for IBT and -0.45 for DBT (AP); -0.637 for IBT and -0.319 for DBT (other)	-0.45 to -0.22 (DBT) 0.57 to 0.63 (IBT)	Precipitation: -0.33 to 0.015, temperature: 1.43 to 2.18, household size: -0.93 to -0.27 (IBT) and 0.21 to 0.35 (DBT), conservation programme: -0.17 to -0.01
Point	1993	Uniform price and block tariffs	-0.167	-	-
Lyman	1992	Two-part tariff	Peak: -2.019 to -1.354; Off-peak: -0.512 to -0.395	0.084 to 0.147	-
Martin and Wilder	1992	Fixed charge + uniform rate	-0.60 to -0.32 (MP) and -0.70 to -0.49 (AP)	0.04 to 0.27	-
Nieswiadomy	1992	Block tariffs	-0.17 to -0.02 (MP), -0.60 to -0.22 (AP) and -0.45 to -0.29 (price perception model)	0 to 0.44	Precipitation: -0.26 to 0; temperature: 0 to 3.83; household size: 0 to 0.73

Authors	Year of publication	Type of tariff structure	Price-elasticity	Income-elasticity	Other elasticities
Renzetti	1992	-	-1.193 (industrial); -0.6487 (residential, summer); -0.0137 (residential, winter)	0.9097 (residential, summer); 0.5515 (residential, winter)	0.785 (output-elasticity of industrial demand)
Stevens et al.	1992	Uniform price, IBT and DBT	-0.69 to -0.10	-	-
Woo	1992	DBT (residential); Unifrom price (commercial)	-0.384	0.278	Monthly supply hours: 0.153; net precipitation: 0; temperature: 0.01
Griffin and Chang	1991	Flat rates, uniform price, IBT and DBT	-0.476 to -0.114	0.128	Precipitation: -0.154; number of days without precipitation: 0.649
Nieswiadomy and Molina	1991	IBT (1976-1980) and DBT (1981-1985)	-0.110 (DBT); - 0.295 (IBT)	0.088 to 0.186	Lawn size: 0.147 to 0.235; weather: 0.463 to 1.744
Rizaiza	1991	-	-0.78 to -0.22	0.09 to 0.49	Household size: 0.44 to 0.73; Temperature: 0.94 to 1.26
Schneider and Whitlatch	1991	Minimum charge plus 5 DBT	-0.262 (long-run); -0.119 (short-run) (residential); -0.918 (long-run) -0.236 (short-run) (commercial); -0.438 (long-run, industrial); -0.781 (long-run) -0.438 (short-run) (government) -0.956 (long-run) -0.369 (short-run) (schools); -0.50 (long-run) -0.14 (short-run) (total metered)	0.207 (residential); 1.97 (commercial); 0.895 (government); 0.487 (school); 0.231 (total metered)	Household size: 0.306 (residential); 0.385 (commercial); 0.683 to 0.968 (government); 0.407 (school); 0.26 to 2.51 (total metered). Housing composition: -0.66 (residential); -0.93 (total metered). Summer precipitation: 0.145 (residential); -0.169 (total metered)

Authors	Year of publication	Type of tariff structure	Price-elasticity	Income-elasticity	Other elasticities
Billings	1990	IBT	-0.717 to -0.565 (long-run); -0.50 to -0.36 (short-run)	0.296 to 0.300	Household size: 0.136 to 0.221; Temperature: 0.516 to 0.742; Precipitation: -0.053 to -0.019
Griffin and Chang	1990	Block tariffs	-0.19 to -0.16 in th winter and -0.38 to -0.37 in the summer (AP)	0.48 (winter); 0.30 (summer)	-
Miaou	1990	Flat fee for first m3 + DBT	-0.354 to -0.174	-	Precipitation: -0.098 to -0.056; summer temperature: 0.320 to 0.410; average monthly temperature: 1.167
Mu et al.	1990	Uniform price, IBT and DBT	-	0.07	Collection time: -0.16; years of formal education: 0.06; proportion of women: 0.26
Billings and Day	1989	Fixed charge + uniform rate or IBT and seasonal rate	-0.72 (overall price-elasticity); -0.52 (MP) and -0.70 (AP)	0.31 to 0.36	Difference variable: -0.21; temperature: 0.63 to 0.81; Summer precipitation: -0.06; publicity about water problems: -0.05 to -0.04; household size: 0.16 to 0.48; aged 65 or older: -0.13 to 028
Moncur	1989	Uniform price and DBT	-0.05	-	-
Nieswiadomy and Molina	1989	IBT (1976-1980) and DBT (1981-1985)	-0.86 to -0.36	0.11 to 0.24	Lawn size: 0.25 to 0.38; house size: 0.18 to 0.27; weather: 0.58 to 0.73

Authors	Year of publication	Type of tariff structure	Price-elasticity	Income-elasticity	Other elasticities
Weber	1989	-	-0.25 to -0.1	-	-
Wilson	1989	-	-0.5	0.6	Moisture deficit: 1.3
Nieswiadomy and Molina	1988	IBT	-	0.13 to 0.31	-
Palencia	1988	IBT (first blocks have a charge which is fixed within the block and increasing from one block to the next)	-0.287	0.542	-
Thomas and Syme	1988	Flat rates (until 1977/78) and uniform rates with free allowances (after 1978/79)	TS: -0.43 to -0.01; CV: -0.18 (total); -0.04 (indoor); -0.31 (outdoor) (decreasing with income level, increasing with household size)	0.2	-
Agthe and Billings	1987	IBT + seasonal pricing	-0.565 (low income) to -0.397 (high income)	-	-
Billings	1987	Fixed charge plus IBT	-0.5 to -0.06	-	-
Frerichs et al.	1987	Block tariffs	-0.21 to -0.17 (MP) and -0.27 to -0.19 (AP)	0.6	Household size: 0.5; proportion of youth: -0.43

Authors	Year of publication	Type of tariff structure	Price-elasticity	Income-elasticity	Other elasticities
Moncur	1987	Uniform price and DBT	Short-run: -0.517 to -0.032; Long-run: -0.683 to -0.1	0.038 to 0.080	-
Schefter	1987	IBT plus fixed charge	-0.13	0.65	-
Agthe et al.	1986	Service availability charge plus IBT	-0.624 (long-run); -0.364 (short-run)	-	Difference: -0.247 (long-run); -0.136 (short-run)
Chicoine and Ramamurthy	1986	DBT	-0.47	-	-
Chicoine et al.	1986	DBT	-0.42 to -0.22	0.01 to 0.14	-0.29 to -0.27 (second price-related variable)
Deller et al.	1986	DBT	-1.12 to -0.36 (average of -0.76)	-	-
Martin and Thomas	1986	Service charge + IBT (Phoenix and Tucson); Service charge + Uniform rate after initial free allowance (Perth); Uniform rate (Coober Peddy and Kuwait)	-0.50	-	-
Williams and Suh	1986	Block tariffs	Residential: -0.484 to 0.179; Commercial: -0.360 to -0.141; -0.976 to -0.438 (industrial)	0.579 to 0.972	Temperature: 0.02; precipitation: -0.19 to -0.09; industrial output: 0.18 to 0.30
Al-Qunaibet and Johnston	1985	-	-0.976 to -0.771	-0.012 to 0.211	-
Cochran and Cotton	1985	Flat fee for first m3 + DBT	-0.40	0.58	-

Authors	Year of publication	Type of tariff structure	Price-elasticity	Income-elasticity	Other elasticities
Schefter and David	1985	Block tariffs	-0.127 to -0.109	-	-
Jones and Morris	1984	DBT, IBT (up to 4 blocks) and uniform prices	-0.44 (log-log model) to -0.14 (linear model)	0.40 to 0.55	Household size: 0.09 to 0.17
Young et al.	1983	Uniform price (1974-1978); IBT (1979)	-	-	-
Billings	1982	IBT	-0.66 to - 0.56	0.0521 to 2.14	Difference: -0.087 to -0.075; Sewer charge: 0.101
Hanke and de Maré	1982	Uniform price	-0.15	0.11	Number of adults: 0.13; Number of children: 0.05; precipitation: -0.21
Howe	1982	Uniform price and DBT	-0.568 to -0.427 (summer) and -0.06 (winter)	-	-
Ford and Ziegler	1981	DBT	-1.613 to -0.853 (estes valores estão errados porque são os coeficientes na equação semilogarítmica)	-	-
Foster and Beattie	1981	DBT	-	-	-

Authors	Year of publication	Type of tariff structure	Price-elasticity	Income-elasticity	Other elasticities
Agthe and Billings	1980	IBT	Short-run: -2.226 to -0.179. Long-run: -0.705 to -0.266	Short-run: 1.33 to 7.829. Long-run 1.70 to 2.77.	Difference: Short-run: -0.412 to -0.087. Long-run: -0.149 to -0.119.
Ben-zvi	1980	DBT	-0.73 (non-industrial); '-0.79 (winter nonindustrial); -0.82 (summer, nonindustrial); -2.42 (food industry); -0.56 (lumber and paper); -1.47 (chemicals); -0.15 (petroleum); -1.13 (stone and clay)	-	-
Billings and Agthe	1980	Fixed charge plus IBT	From -0.267 to -0.45	1.68	Difference: From -0.30 to -0.123; Sewer charge: 0.0897
Carver and Boland	1980	Uniform price and block tariffs	Nonseasonal: Short-run: -0.05 to -0.02; Long-run: -0.7 to -0.02;: Seasonal: -0.11 to -0.10 in the short-run and 0.11 in the long-run	-	-
Cassuto and Ryan	1979	-	-0.39 to -0.14	-	-
Colander and Haltiwanger	1979	Flat fee for first m3 + DBT	-0.14 to 0.09	-	Precipitation: -0.21 to -0.04
Danielson	1979	DBT	-0.272 (total); -0.305 (indoor) and -1.38 (outdoor)	0.334 to 0.363	Household size: 0.74; precipitation: -0.018 (total); -0.206 (outdoor): temperature: 0.316 (total); 5.141 (outdoor)
Foster and Beattie	1979	DBT	-0.76 to -0.27	0.6274	Precipitation: -0.0403; numer of persons per meter: 0.3026
Camp	1978	-	-0.35 to -0.03	0 to 0.14	-
Gibbs	1978	DBT and uniform price (some cases with flat rates for the first m3)	-0.51 (MP) and -0.62 (AP)	0.51 to 0.8	-

Authors	Year of publication	Type of tariff structure	Price-elasticity	Income-elasticity	Other elasticities
Katzman	1977	Uniform price	-0.1 to -0.2	0 (low income families); 0.2 to 0.4 (higher income families)	-
Clark	1976	-	-0.63 to -0.17	-	-
Grunewald et al.	1976	-	-0.92	-0.14 (not significantly different from 0)	-
Morgan and Smolen	1976	-	-0.65 to -'0.43	0.24 to 0.67	-
Andrews and Gibbs	1975	DBT; free first block after paying a fixed cahrge	-0.62 (AP); -0.51 (MP)	0.51	-
Attanasi et al.	1975	Block tariffs	-2.19 to 0.81 (residential); -3.02 to -1.08 (commercial); -1.33 to -0.23 (industrial)	0.08 to 0.21 (residential); 0.02 to 0.10 (commercial)	Output elasticity: 0.01 to 0.21 (industrial)
Batchelor	1975	Uniform price	-	0.38 to 0.93	-
Darr et al.	1975	-	-	0.17 to 0.60	Household size: -1.01 to -0.28
Hogarty and MacKay	1975	Fixed charge plus uniform price with free allowance or DBT	-0.86 to -0.56	-	-
Morgan	1974	Two-part tariff	-0.49	-	-

Authors	Year of publication	Type of tariff structure	Price-elasticity	Income-elasticity	Other elasticities
Grima	1973	DBT plus fixed charge	-1.07 (summer) to -0.75 (winter) (variable price); -0.35 (summer) to -0.24 (winter) (fixed bill)	0.48 to 0.56	Household size: 0.59 to 0.63
Morgan	1973	Uniform price	-	0.33 to 0.31	Household size: 0.25 to 0.57
Young	1973	Flat fee for first m3 + DBT	-0.65 to -0.41	-	Precipitation: -0.14 to -0.03
Wong	1972	Flat rate and uniform rate	-0.283 to -0.018 (time-series); -0.817 to -0.257 (cross-section)	0.195 to 0.258 (time-series); 0.476 to 1.025 (cross-section)	Summer temperature: 0.410 to 1.257
Hanke and Davis	1971	Block tariffs	-0.10 (residential indoor); -1.57 to -1.25 (residential outdoor); -0.10 (commercial/ industrial)	-	-
Hanke	1970	Initial flat rate changed to a uniform price after metering is universally installed	-	-	-
Turnovsky	1969	Uniform price	-0.406 to -0.049 (residential); -0.839 to -0.473 (industrial)	1.00 to 2.39	% of population <18: 0.73 to 1.18
Meroz	1968	Flat rates and volumetric rates	-0.53 to -0.43	0.33 to 0.41	-
Conley	1967	-	-1.09 to -1.02	-	-
Howe and Linaweaver	1967	Uniform price and DBT	-0.23 (indoor) -1.57 to -0.7 (outdoor)	0.4 to 1.5	-
Bain et al.	1966	-	-1.099	-	-
Flack	1965	-	-0.61 to -0.12	-	-

Authors	Year of publication	Type of tariff structure	Price-elasticity	Income-elasticity	Other elasticities
Gardner and Schick	1964	-	-0.77	-	-
Gottlieb	1963	-	-0.39 to -1.23	0.28 to 0.89	-
Headley	1963	Uniform price	-	0 to 0.37	-
Fourt	1958	-	-0.386	-	-
Seidel and Baumann	1957	Flat rates and volumetric rates	-1 to -0.12	-	-
Larson and Hudson	1951	-	-	0.7	-
Metcalf	1926	-	-0.65	-	-

Appendix D

Water cost function estimation studies

Authors	Year of Publication	Where Published	Type of data	Data years	Cost function vs Cost frontier	Econometric method	Number of observations	Study area	Functional form
Bottasso and Conti	2009	Regional Science and Urban Economics	Panel data	1995-2005	Cost function	RE; PCSE (panel corrected standard errors); SUR	144 (unbalanced panel)	England (UK)	Translog
Farsi and Filippini	2009	Energy Economics	Panel data	1997-2005	Cost frontier	RE, GLS, ML	306 (34 utilities*9 years)	Switzerland	Translog
Tsegai et al.	2009	ZEF - Center for Development Research, Universität Bonn, Discussion Papers on Development Policy	Panel data	2004 and 2006	Cost function	SUR	100 (50 water utilities*2 years)	Middle Olifants (South Africa)	Translog
Urakami and Parker	2009	Paper presented at the 36th annual conference of EARIE - European Association of Industrial Economics	Panel data	1999-2006	Cost function	SUR	12952 (unbalanced panel)	Japan	Translog
Urakami and Tanaka	2009	Paper presented at the 4th International Symposium on Economic Theory, Policy and Applications, ATINER	Panel data	1999-2006	Cost function	SUR	8327 (unbalanced panel)	Japan	Pulley and Braunstein composite Cost function
Bouscasse et al.	2008	Revue d'économie industrielle	Cross-section	1996	Cost frontier	SUR	332	USA	Translog
Farsi et al.	2008	Energy Journal	Panel data	1997-2005	Cost function	RE, GLS, Random coefficients	622 (unbalanced panel)	Switzerland	Quadratic
Filippini et al.	2008	Journal of Productivity Analysis	Panel data	1997-2003	Cost frontier	FE, ML, Pooled OLS; RE(GLS) and RE(ML)	332 (unbalanced panel)	Slovenia	Translog
Iimi	2008	Policy Researc Working Paper - The World Bank	Panel data	1993-...	Cost function	OLS, SUR	306 (unbalanced panel)	Low and Middle Income Countries (Private Participation in Infrastructure (PPI) Project Database - The World Bank)	Translog
Martins et al.	2008	WP - Estudos do GEMF: Monetary and Financial Research Group, School of Economics, University of Coimbra	Cross-section	2002	Cost function	ML: Broyden, Fletcher, Goldfarb, Shanno (BFGS) algorithm	265	Portugal	Quadratic

Authors	Year of Publication	Where Published	Type of data	Data years	Cost function vs Cost frontier	Econometric method	Number of observations	Study area	Functional form
Nauges and Berg	2008	Journal of Regulatory Economics	Panel data	1996-2004	Cost function	SUR	537 (unbalanced panels: Brazil: 204; Moldova: 72; Romania: 107; Vietnam: 154)	Brazil, Moldova, Romania and Vietnam	Translog
Nauges and Berg	2008	unpublished	Panel data	1996-2004 (unbalanced, variable by country)	Cost function	SUR	Variable by country equation	Brazil, China, Colombia, Cote d'Ivoire, Czech Republic, Hungary, Malawi, Moldova Republic, Nigeria, Philippines, Romania, Togo, Vietnam and Zambia	Translog
Sabbioni	2008	Utilities Policy	Panel data	2000-2004	Cost function	FE	1163 (unbalanced panel)	Brazil	Linear
Sampaio	2008	Paper presented at the 5th Portuguese-Mozambican Congress of Engineering	Panel data	2000-2001	Cost frontier	ML	430 (215 municipalities*2 years)	Portugal	Double logarithmic, loglinear or log-log (from Cobb-Douglas)
Souza et al.	2008	Estudios Econômicos	Panel data	2002-2004	Cost frontier	ML	1026 (342 utilities* 3years)	Brazil	Double logarithmic, loglinear or log-log (from Cobb-Douglas)
Garcia et al.	2007	International Journal of Industrial Organization	Panel data	1997-2000	Cost function	RE (GMM and Hausman-Taylor instruments) and FE+SUR; Probit (for the vertical integration decision)	844 (211 utilities*4 years)	Wisconsin (USA)	Translog
Urakami	2007	Jahrbuch für Regionalwissenschaft	Cross-section	2003	Cost function	SUR	561	Japan	Translog
Kirkpatrick et al.	2006	The World Bank Economic Review	Cross-section	2000	Cost frontier	ML	76	Africa	Double logarithmic, loglinear or log-log (from Cobb-Douglas)
Martins et al.	2006	WP - Estudos do GEMF: Monetary and Financial Research Group, School of Economics, University of Coimbra	Cross-section	2002	Cost function	OLS	282	Portugal	Cubic
Shih et al.	2006	Journal of the American Water Works Association	Panel data	1995 and 2000	Cost function	Pooled OLS	264 (132 utilities*2 years)	USA	Double logarithmic, loglinear or log-log (from Cobb-Douglas)

Authors	Year of Publication	Where Published	Type of data	Data years	Cost function vs Cost frontier	Econometric method	Number of observations	Study area	Functional form
Torres and Paul	2006	Journal of Urban Economics	Cross-section	1996	Cost function	FIML	255	USA	Generalized Leontief quadratic
Aubert and Reynaud	2005	Journal of Productivity Analysis	Panel data	1998-2000	Cost frontier	ML	633 (211 utilities*3 years)	Wisconsin (USA)	Translog
Fraquelli and Moiso	2005	WP - HERMES - Higher Education on Research and Mobility Regulation and the Economics of Local Services	Panel data	20-30 years	Cost frontier	ML	407 (unbalanced panel)	Italy	Translog
Garcia-Valiñas	2005	Environmental and Resource Economics	Time-series	1985-2000	Cost function	SUR	6	Seville (Spain)	Double logarithmic, loglinear or log-log (from Cobb-Douglas)
Garcia-Valiñas	2005	Revista de Economía Pública	Time-series	1985-2000	Cost function	SUR	6	Elche (Spain)	Double logarithmic, loglinear or log-log (from Cobb-Douglas)
Lin	2005	Utilities Policy	Panel data	1996-2001	Cost frontier	FE, RE, ML	198 (unbalanced panel)	Peru	Double logarithmic, loglinear or log-log (from Cobb-Douglas)
Sauer	2005	Water Resources Research	Cross-section	2000-01	Cost function	SUR	47	Germany	Symmetric Generalized McFadden
Urakami	2005	Paper presented at the ERSA 2005 conference	Cross-section	2001-2002	Cost function	ML	1346 (132: bulkwater only utilities; 1924: retail utilities with own intake sources and distribution; 290: retail utilities buying water from bulk operators)	Japan	Translog
Fraquelli et al.	2004	Applied Economics	Panel data	1994-1996	Cost function	NLSURE	270 (90 utilities*3 years)	Italy	Pulley and Braunstein composite Cost function; Translog; Quadratic
Garcia and Reynaud	2004	Resource and Energy Economics	Panel data	1995-1998	Cost function	GMM (Hausman-Taylor instruments)	200 (50 utilities*4 years)	Bordeaux (France)	Translog
Kirshen et al.	2004	Water Policy	Cross-section	1995	Cost function	OLS	1363	USA	Double logarithmic, loglinear or log-log (from Cobb-Douglas)
Piacenza and Vannoni	2004	Economics Letters	Panel data	1994-1996	Cost function	NLSURE	270 (90 utilities*3 years)	Italy	Pulley and Braunstein composite Cost function; Translog; Quadratic
Saal and Reid	2004	WP - Aston Business School	Panel data	1993-2003	Cost function	ML	110 (10 privatized utilities*11 years)	England and Wales (UK)	Translog

Authors	Year of Publication	Where Published	Type of data	Data years	Cost function vs Cost frontier	Econometric method	Number of observations	Study area	Functional form
Stone & Webster Consultants	2004	Technical Report	Panel data	1992-2003	Cost function	SUR	290 (unbalanced panel)	England and Wales (UK)	Translog, quadratic
Urakami	2004	Paper presented at the ERSA 2004 conference	Cross-section	2001	Cost function	SUR	1803	Japan	Translog
Ashton	2003	The Service Industries Journal	Panel data	1991-1996	Cost function	SUR	120 (20 utilities*6 years)	England and Wales (UK)	Translog
Bottasso and Conti	2003	WP - University of Essex, Department of Economics	Panel data	1995-2001	Cost frontier	ML	177 (unbalanced panel)	England and Wales (UK)	Translog
Corton	2003	Utilities Policy	Cross-section	1998	Cost frontier	OLS	44	Peru	Double logarithmic, loglinear or log-log (from Cobb-Douglas)
Fraquelli and Giandrone	2003	Water Resources Research	Cross-section	1996	Cost function	Restricted least squares	103	Italy	Loglinear (from Cobb-Douglas)
Garcia and Thomas	2003	Environmental and Resource Economics	Panel data	1995-1998	Cost function	SUR	192 (48 utilities*4 years)	Bordeaux (France)	Translog
Estache and Rossi	2002	The World Bank Economic Review	Cross-section	1995	Cost frontier	OLS and ML	50	29 Asian and Pacific countries (Bangladesh, Butan, Cambodia, China, Hong Kong, Taiwan, Cook Islands, Fiji, India, Indonesia, Kasakhstan, South Korea, Kyrgyztan, Laos, Malaysia, Maldives, Mongolia, Myanmar, Nepal, Pakistan, Papua New Guinea, Phillipines, Singapore, Solomon Islands, Sri Lanka, Thailand, Tonga, Uzbekistan, Vanuatu, Vietnam and Samoa)	Double logarithmic, loglinear or log-log (from Cobb-Douglas)
Antonioli and Filippini	2001	Utilities Policy	Panel data	1991-1995	Cost function	OLS and RE	160 (32 utilities*5 years)	Italy	Double logarithmic, loglinear or log-log (from Cobb-Douglas)
Garcia and Thomas	2001	Journal of Productivity Analysis	Panel data	1995-1997	Cost function	3-step GMM (with Hausman-Taylor instruments); SUR	165 (55 utilities*3 years)	Bordeaux (France)	Translog

Authors	Year of Publication	Where Published	Type of data	Data years	Cost function vs Cost frontier	Econometric method	Number of observations	Study area	Functional form
Mizutani and Urakami	2001	Papers in Regional Science	Cross-section	1994	Cost function	SUR	112	Japan	Translog; Translog with hedonic specification of output; Double logarithmic, loglinear or log-log (from Cobb-Douglas)
Ashton	2000	Applied Economics Letters	Panel data	1987-1997	Cost function	FE	110 (10 privatized utilities*11 years)	England and Wales (UK)	Translog
Ashton	2000	The Service Industries Journal	Panel data	1989-1997	Cost function	SUR	90 (10 privatized utilities*9 years)	England and Wales (UK)	Translog
Fabbri and Fraquelli	2000	Empirica	Cross-section	1991	Cost function	SUR	173	Italy	Translog; Double logarithmic, loglinear or log-log (from Cobb-Douglas)
Saal and Parker	2000	Managerial and Decision Economics	Panel data	1985-1999	Cost function	NLSURE	150 (10 privatized utilities*15 years)	England and Wales (UK)	Translog
Renzetti	1999	Canadian Journal of Economics	Cross-section	1991	Cost function	SUR	77	Ontario (Canada)	Translog
Cubbin and Tzanidakis	1998	Utilities Policy	Cross-section	1994-1995	Cost frontier	OLS	29	England and Wales (UK)	Double logarithmic, loglinear or log-log (from Cobb-Douglas)
Bhattacharyya et al.	1995	Regional Science and Urban Economics	Cross-section	1992	Cost frontier	SUR	221	USA	Translog
Bhattacharyya et al.	1995	Journal of Regional Science	Cross-section	1992	Cost frontier	SUR	26	Nevada (USA)	Symmetric Generalized McFadden
Hunt and Lynk	1995	Oxford Bulletin of Economics & Statistics	Panel data	1979/80-1987/88	Cost function	OLS	90 (10 utilities*9 years)	England and Wales (UK)	Translog
Kim	1995	Review of Industrial Organization	Cross-section	1973	Cost function	SUR	60	USA	Translog
Bhattacharyya et al.	1994	Land Economics	Cross-section	1992	Cost function	NLSURE	257	USA	Translog
Lynk	1993	Fiscal Studies	Panel data	1979/80-1987/88 (water and wastewater companies); 1984/85-1987/88 (water only companies)	Cost frontier	OLS	90 (10 utilities*9 years) (water and wastewater companies); 88 (22 utilities*4 years) (water only companies)	England and Wales (UK)	Translog
Price	1993	Technical Report - OFWAT	Cross-section	1991-1992	Cost function	OLS	32	England and Wales (UK)	Linear
Raffiee et al.	1993	Atlantic Economic Journal	Cross-section	1989	Cost frontier	OLS	271	USA	Double logarithmic, loglinear or log-log (from Cobb-Douglas)

Authors	Year of Publication	Where Published	Type of data	Data years	Cost function vs Cost frontier	Econometric method	Number of observations	Study area	Functional form
Renzetti	1992	Journal of Environmental Economics and Management	Time-Series	1975-1986 (quarterly data)	Cost function	2SLS	48	Vancouver (Canada)	Translog
Male et al.	1991	Water Resources Bulletin	Cross-section	1987	Cost function	OLS	150	USA	Double logarithmic, loglinear or log-log (from Cobb-Douglas)
Kim and Clark	1988	Regional Science and Urban Economics	Cross-section	1973	Cost function	SUR	60	USA	Translog
Hayes	1987	Applied Economics	Cross-section	1960, 1970 and 1976	Cost function	OLS	475	USA	Quadratic
Kim	1987	Economica	Cross-section	1973	Cost function	SUR	60	USA	Translog
Teeples and Glyer	1987	Review of Economics and Statistics	Cross-section	1980	Cost function	SUR	119	Southern California (USA)	Translog
Teeples and Glyer	1987	Water Resources Research	Cross-section	1980	Cost function	SUR	119	Southern California (USA)	Translog; Box-Cox transformation
Fraas and Munley	1984	Journal of Environmental Economics and Management	Cross-section	1978	Cost function	OLS	62 (capital cost equation); 178 (operation and maintenance cost equation)	USA	Double logarithmic, loglinear or log-log (from Cobb-Douglas)
Feigenbaum and Teeples	1983	Review of Economics & Statistics	Cross-section	1970	Cost function	Nonlinear ML	319	USA	Translog (Double logarithmic, loglinear or log-log (from Cobb-Douglas) for the output hedonic function)
Clark and Stevie	1981	Land Economics / Growth and Change	Cross-section	1977	Cost function	OLS	12	USA	Double logarithmic, loglinear or log-log (from Cobb-Douglas)
Crain and Zardkoohi	1978	Journal of Law and Economics	Cross-section	1970	Cost function	OLS	112	USA	Double logarithmic, loglinear or log-log (from Cobb-Douglas)

Authors	Year of Publication	Where Published	Type of data	Data years	Cost function vs Cost frontier	Econometric method	Number of observations	Study area	Functional form
Knapp	1978	Journal of Industrial Economics	Cross-section	1972/1973	Cost function	OLS	172	England and Wales (UK)	Hyperbolic
Ford and Warford	1969	Journal of Industrial Economics	Cross-section	1965-66	Cost function	OLS	162	England and Wales (UK)	Quadratic; semilogarithmic; double logarithmic, loglinear or log-log (from Cobb-Douglas)
Hines	1969	Land Economics	Panel data	1945-1957	Cost function	OLS	52	Wisconsin (USA)	Linear

Authors	Year of Publication	Variables used					
		Dependent variable - cost function	Input prices	Volumes supplied/drained	Number of customers	Length of the water distribution network	Others
Bottasso and Conti	2009	Variable cost	Price of labor, capital and others	Water supplied	Number of customers	Service area size	Capital stock; water quality indices; time trend; average pumping head; % of water from river sources; density of operations (population/length of the water mains); % of water delivered to nonresidential customers
Farsi and Filippini	2009	Total cost	Price of labor, capital, electricity and purchased gas	Water, gas and electricity supplied	Customer density (Electricity customers/area)	-	Year dummies
Tsegai et al.	2009	Variable cost	Price of labour, capital and materials	Water supplied	-	-	Year dummies
Urakami and Parker	2009	Total cost	Price of labour, capital and other costs	Water supplied (hedonic specification for the output, regressed on coverage ratio, dam ratio, underground ratio and daily supplied water per person	Population density	-	Capacity utilization; purchased water ratio; time trend; dummies for consolidation (consolidation years, and utilities consolidated during sample period
Urakami and Tanaka	2009	Total cost	Price of labour, capital and other costs	Water supplied (hedonic specification for the output, regressed on coverage ratio, dam ratio, underground ratio and daily supplied water per person)	Population density	Capacity utilization	Purchased water ratio; time trend; dummies for consolidation (consolidation years, and utilities consolidated during sample period
Bouscasse et al.	2008	Variable cost	Price of labor, energy and others	Water supplied	Number of customers	Length of the water distribution network	Quality level of the delivered services (number of complaints per day per 1000 customers); ratio of water losses to network length; % of water produced from groundwater sources (as proxy for water quality); dummy variable for public ownership (instrumented from the remaining variables); stocking capacity
Farsi et al.	2008	Total cost	Price of labor, capital, electricity and purchased gas	Water, gas and electricity supplied	Customer density (Electricity customers/area)	-	Sector specific time trends, dummies for inputs used and sector of outputs
Filippini et al.	2008	Total cost	Price of labor, capital and material	Water supplied	Number of customers	Service area size	Time variable to capture the shift in technology; dummy variable for water losses (=1 if water losses are "low") treatment (=1 if water is treated chemically before distribution); surface water sources (=1 if water is produced only from surface sources) underground water sources (=1 if water is produced only from underground sources)
Iimi	2008	Variable cost	Price of labor and other operation and maintenance	Water Supplied; sewage collected	Number of water connections; number of sewage connections	-	Dummies for type of procurement contract (affermage, concession transaction, divestiture, lease contracts and management contracts)
Martins et al.	2008	Total cost	-	Water supplied; water losses	Customer density	Length of the water distribution network	Proportion of raw water acquired from other utilities; type of utility management, existence of economic regulation; dummy variables related to the Portuguese hydrographical regions

Authors	Year of Publication	Variables used					
		Dependent variable - cost function	Input prices	Volumes supplied/drained	Number of customers	Length of the water distribution network	Others
Nauges and Berg	2008	Variable cost	Price of labor, energy, contracted out services and others	Water produced and wastewater treated (Brazil, Moldova and Romania; for Vietman a single output cost function is estimated based on water produced)	Population served per utility (number of connections); Number of towns served	Length of the water distribution network	Share of total volume sold to residential users per utility; duration of supply (hours per day); number of pipe breaks per kilometre of network per year; % of contracted out services costs; % of energy costs; % of labor costs; % of metered connections
Nauges and Berg	2008	Variable cost	Price of labor, energy, contracted out services and others	Water produced and wastewater treated	Number of towns served	Length of the water distribution network	Duration of supply (hours per day); Number of pipe breaks per kilometre of network per year; efficiency as measured by the ratio of total volume sold over total volume produced
Sabbioni	2008	Variable cost	Price of labor	Water produced	Number of customers	Length of the water distribution network	Dummy for the provision of sewerage services by the water utility; % of urban population; % of metered connections; Fluorination index as a proxy for water quality; Year dummies
Sampaio	2008	Variable cost	Price of labor and capital	Water supplied	Number of customers	Length of the water distribution network	Population density; dummy variable for type of source; % of lacking mandatory water quality analysis
Souza et al.	2008	Total Cost	Price of labor and capital	Water produced	-	-	Dummies for year, type of firms; private ownership and region. Population density; % of water treated
Garcia et al.	2007	Variable cost	Price of labor, energy, chemicals, operation supplies and expenses, maintenance and water purchased	Water supplied at the retail and at the wholesale level	Number of customers	Length of the water distribution network	Pumping capacity; Storage capacity; network rate of return (volume produced/volume distributed)
Urakami	2007	Total Cost	Prices of labor, capital, chemicals, purchased water and others	Water supplied	-	-	% of purchased water in total water delivered
Kirkpatrick et al.	2006	Variable cost	Price of labor and materials	Water supplied	-	-	Hours of piped water availability per day; freedom variable developed by the Fraser Institute as a proxy for good governance; fiscal balance as a proxy for macroeconomic management quality; index of property rights; population/number of connections; per capita annual water resources; Gross Domestic Product per capita; dummy for utilities with private capital
Martins et al.	2006	Total Cost	-	Water supplied; wastewater collected	Customer density in water supply; number os wastewater customers	-	Dummy variable for private company
Shih et al.	2006	Unit cost	-	Water produced	-	-	Dummies for public ownership and for water source (surface, purchased vs. groundwater)

Authors	Year of Publication	Variables used					
		Dependent variable - cost function	Input prices	Volumes supplied/drained	Number of customers	Length of the water distribution network	Others
Torres and Paul	2006	Variable cost	Price of labor, energy and purchased water	Water sold to wholesale and/or sold to final consumers	Number of customers	Service area size	Storage and treatment capacity, % of water produced from groundwater sources; expenditures on chemicals
Aubert and Reynaud	2005	Variable cost	Price of labor and energy	Water supplied	Number of customers	-	Capital (value of assets); dummy for water purchased from other water utilities; dummy for water produced from surface sources; time dummies; average pumping depth
Fraquelli and Moiso	2005	Total Cost	Price of labor, capital, energy, materials and services	Water supplied	-	Length of the water distribution network	Dummy for water losses (=1 if greater than average); time trend
Garcia-Valiñas	2005	Variable cost; Total cost	Price of labor, capital and energy	Water supplied	-	Length of the water distribution network	-
Garcia-Valiñas	2005	Variable cost; Total cost	Price of labor, capital, energy and bulk water	Water supplied	-	Length of the water distribution network	-
Lin	2005	Total Cost	Price of labor and capital	Water supplied	Number of customers	-	Accounted-for water ratio (watersupplied/water produced), positive rate of chlorine tests, service coverage and service continuity
Sauer	2005	Variable cost	Price of labor, energy and chemicals	Water supplied	Number of customers	Length of the water distribution network	% of groundwater intake
Urakami	2005	Total Cost	Price of labor, capital, bulk water and others	Water supplied	-	-	dummy variables for dam water and groundwater
Fraquelli et al.	2004	Total Cost	Price of labor and others	Water, gas and electricity supplied	-	-	-
Garcia and Reynaud	2004	Variable cost	Price of labor, energy and materials	Water supplied	Number of customers	Length of the water distribution network	rate of return on water produced (water supplied/water produced)
Kirshen et al.	2004	Total Cost	Price of energy and construction cost	Water supplied	-	-	Precipitation; temperature; average annual streamflow; water withdrawals; ratio of groundwater outflow to streamflow; aridity (ratio of evapotranspiration to rainfall); storage capacity
Piacenza and Vannoni	2004	Total Cost	Price of labor and others	Water, gas and electricity supplied	-	-	-
Saal and Reid	2004	Variable cost	Price of labor and others	Water supplied and wastewater collected	Number of connections to the water supply network and to the sewerage network; sewerage service density and water service density	-	Firm dummy; water supply capital stock; sewerage capital stock; three relative measures of drinking water quality

Authors	Year of Publication	Variables used					
		Dependent variable - cost function	Input prices	Volumes supplied/drained	Number of customers	Length of the water distribution network	Others
Stone & Webster Consultants	2004	Variable cost and total cost	Price of labor, capital, energy and others	water supplied and wastewater collected	Number of water supply connections; equivalent population served	-	Capital stock; firm dummy; drinking water quality indices; % of population receiveing secondary sewage treatment; number of properties below the required level of water pressure; number of properties with supply interruptions >12h; number of properties at risk of sewer flooding; % of metered billed properties; average pumping head; % of water from river sources; % of wastewater from trade effluent customers
Urakami	2004	Total cost	Price of labor, capital and others	Water supplied	-	Length of the water distribution network	Purchased water ratio; Subsidies
Ashton	2003	Variable cost	Price of labor and others	Residential water supplied	Customer density	-	Capital stock, time trend
Bottasso and Conti	2003	Variable cost	Price of labor and others	Water supplied and water produced	Population density	Length of the water distribution network	Dummy for sewerage service; average pumping head; % of river sources; % of water delivered to nonresidential customers; capital stock
Corton	2003	Variable cost	-	Water produced	-	Length of the water distribution network	number of districts administered by each company (in logs or through dummies); regional dummies; service coverage
Fraquelli and Giandrone	2003	Variable cost	Price of labour, materials and sludge disposal	Wastewater treated	-	-	Difference in chemical oxygen demand between influent and effluent wastewater; ratio of the excess sludge's mass and the volume of treated water; dummy for tertiary advanced treatment; filter-pressing and centrifuging dehydration processes, mud incineration and mud use in agriculture. Dummy for the integration of sewage collection and water supply
Garcia and Thomas	2003	Total cost	Price of labor, energy, materials and others	Water supplied	-	-	Water loss index (water losses/network length)
Estache and Rossi	2002	Variable cost	Price of labor	Water produced	Number of customers and population density	-	% of water from surface sources; number of hours of water availability per day; % of metered connections; dummy variables for type of treatment and desalination; 3 dummies for private sector participation (concessions; billing collection, leak repair or meter reading; other)
Antonioli and Filippini	2001	Variable cost	Price of labor	Water supplied	Number of customers	Length of the water distribution network	Ratio of water produced to water delivered; number of water wells (proxy for the capital stock); treatment dummy variable; time variable to capture the shift in technology
Garcia and Thomas	2001	Variable cost	Price of labor, energy and materials	Water supplied and water losses	Number of customers	Number of municipalities supplied (proxy for area size); length of the water distribution network	Production capacity; stocking and pumping capacity

Authors	Year of Publication	Variables used					
		Dependent variable - cost function	Input prices	Volumes supplied/drained	Number of customers	Length of the water distribution network	Others
Mizutani and Urakami	2001	Total cost	Price of labor, capital, energy and materials	Water supplied	-	Length of the water distribution network	Utilization rate (water delivery/water intake); variables used as regressors for output in the hedonic output function: treatment level; household ratio; non-dam water acquisition index; non-underground water index
Ashton	2000	Variable cost for water and sewerage	Price of labor, consumables and others	-	Number of customers	-	-
Ashton	2000	Average total cost	Price of labor, capital and consumables	-	Number of customers	-	Time trend
Fabbri and Fraquelli	2000	Total cost	Price of labor, capital-materials, energy and bulk water	Water supplied	Number of customers and customer density	-	Treatment costs
Saal and Parker	2000	Total cost	Price of labor, capital and others	-	Number of customers, adjusted by quality indices	-	Dummies for the years after privatization and after a price review
Renzetti	1999	Total cost (separate for water supply and wastewater)	Price of labor, capital and energy	Water supplied to residential and non-residential customers; wastewater drained	Population density	-	Dummies for type of treatment
Cubbin and Tzanidakis	1998	Variable cost	-	Water supplied	-	Length of the water distribution network	% of water delivered to nonresidential customers
Bhattacharyya et al.	1995	Variable cost	Price of labor, energy and material	Water supplied and water produced	Customer density	Service area size	Stock of capital; types of water sources; quality of water produced; total system loss; dummies for ownership
Bhattacharyya et al.	1995	Variable cost	Price of labor and energy	Water supplied and water produced	Customer density	Ratio number of customers to network length	Stock of capital; % of metered connections; the linear hedonic function for output includes ownership, treatment water source and service diversity (if wastewater is also provided) dummies
Hunt and Lynk	1995	Variable cost	Price of labor	water supplied and wastewater collected (with and without quality adjustments); environmental service	-	-	Firm-specific and time dummies
Kim	1995	Total cost	Price of labor, capital and energy	Residential and nonresidential water supplied	-	Service distance	Capacity utilization
Bhattacharyya et al.	1994	Variable cost	Price of labor, energy and material	Water supplied	-	-	Capital stock; ownership dummy; output price; number of system breakdowns
Lynk	1993	Variable cost	Price of labor	water supplied and wastewater collected (with and without quality adjustments); environmental service	-	-	Firm-specific and time dummies
Price	1993	Average (unit) variable cost	-	Water supplied	-	-	Average pumping head; water sources; % of water delivered to nonredidential customers; % of water produced subject to treatment
Raffiee et al.	1993	Total cost	Price of labor, capital, energy and materials	Water produced	-	-	Ownership dummy

Authors	Year of Publication	Variables used					
		Dependent variable - cost function	Input prices	Volumes supplied/drained	Number of customers	Length of the water distribution network	Others
Renzetti	1992	Total cost	Price of labor (operational and supervisory), capital and bulk water	Water supplied to residential, commercial and industrial customers	Number of customers (only for the long-run model)	-	Stock of capital (replaces price of capital in the short-run-run model)
Male et al.	1991	Total cost	-	Average daily water demand; daily water supplied per connection	-	-	-
Kim and Clark	1988	Total cost	Price of labor, capital and energy	Residential and nonresidential water supplied	-	Service distance	Capacity utilization rate
Hayes	1987	Variable cost (different regressions for each year)	-	Bulk and retail water supplied	-	-	-
Kim	1987	Total cost	Price of labor, capital and energy	Residential and nonresidential water supplied	-	Length of the water distribution network	Capacity utilization rate
Teeples and Glyer	1987	Total cost	Price of labor (divided into field/pumping, distribution maintenance, office/billing and management/engineering), capital-materials, energy, bulkwater purchased and price of own water	Water supplied	Number of customers and customer density	-	Dummy variables for ownership; % of metered connections; number of hydrants per connection of gallon of water delivered; water treatment index; % of water purchased; average storage capacity for average daily delivery
Teeples and Glyer	1987	Total cost	Price of labor (divided into production, office/billing and management/engineering), capital-materials, energy, bulkwater purchased and price of own water	Water supplied to residential and commercial customers, government, agricultural, industrial and others and to unmetered connections	Number of customers and customer density	-	Average storage capacity for average daily delivery; treatment index
Fraas and Munley	1984	Annual cost of wastewater treatment (separate regressions for capital cost and operation and maintenance cost)	-	Wastewater flow	-	-	Average capacity utilization; regional dummies (only for the capital cost equation); concentration of pollutant in the influent and the effluent streams
Feigenbaum and Teeples	1983	Variable cost	Price of labor, capital and energy	Index of firm output (estimated from water supplied, service attributes [index level of water treatment, % of water metered, metered customer density, storage capacity/average daily production, average size (in gallons) of metered account], capital, labor, energy and water inputs)	Number of customers (included in the output hedonic function)	-	-
Clark and Stevie	1981	Water treatment and distribution costs (separate regresssions)	-	Water supplied	-	-	-
Crain and Zardkoohi	1978	Variable cost	Price of labor and capital	Water produced	-	-	Dummy variable for private ownership

Authors	Year of Publication	Variables used					
		Dependent variable - cost function	Input prices	Volumes supplied/drained	Number of customers	Length of the water distribution network	Others
Knapp	1978	Average variable cost	-	Wastewater treated	-	-	% of biochemical oxygen demand removed; degree of water pollution; quantity of suspended solids input and output; Dummies for biological filtration, activated sludge, final effluent treatment, sludge digestion and mechanical de-watering; ratio of dry weather flow to total sewage flow, ratio of sewage flow per population of the served area; number of years since operation commenced or underwent major reconstruction
Ford and Warford	1969	Average (unit) total cost	-	Water supplied	-	Service area size	-
Hines	1969	Average (unit) total, variable and fixed cost cost	-	-	-	-	(Plant investment * capacity utilization) / output

Authors	Year of Publication	Economies of output density	Economies of customer density	Economies of spatial/network density	Economies of scale	Economies of Scope	Economies of Vertical Integration
Bottasso and Conti	2009	2.21 to 4.80	1.05 to 1.70	1.56 to 5.03	0.92 to 1.24	-	-
Farsi and Filippini	2009	-	-	-	-	-	-
Tsegai et al.	2009	-	-	-	1.16; small utilities: 1.149; medium utilities: 1.177; large utilities: 1.156	-	-
Urakami and Parker	2009	-	-	-	1.078 (all water utilities); 1.102 (consolidated water utilities; 1.061 (non-consolidated water utilities)	-	-
Urakami and Tanaka	2009	-	-	-	1.020	0.534 (consolidated water utilities; 0.530 (non-consolidated water utilities)	-
Bouscasse et al.	2008	-	-	-	-	-	-
Farsi et al.	2008	-	-	-	1.03 to 1.24	-0.003 to 0.37	-
Filippini et al.	2008	3.042 to 3.874	1.286 to 1.344	-	1.030 to 1.088	-	-
Iimi	2008	-	1.214	-	1.149	-	-
Martins et al.	2008	-	-	-	1.487	0.327	-

Authors	Year of Publication	Economies of output density	Economies of customer density	Economies of spatial/network density	Economies of scale	Economies of Scope	Economies of Vertical Integration
Nauges and Berg	2008	1.212 to 1.546	0.997 to 1.392	-	1.027 to 1.213	-	-
Nauges and Berg	2008	-	-	-	0.96 to 1.26	-	-
Sabbioni	2008	-	-	-	-	-	-
Sampaio	2008	-	-	-	-	-	-
Souza et al.	2008	-	-	-	-	-	-
Garcia et al.	2007	0.9143 (non-vertically integrated utility); 1,5839 (vertically integrated utility)	-	-	Short-run: 0.9875 (non-vertically integrated production utility); 1.1852 (non-vertically integrated distribution utility); 1.4029 (vertically integrated utility); long-run: 1.1913 (non-vertically integrated distribution utility) 1.1668 (vertically integrated utility	-	0.8 to 1.8
Urakami	2007	-	-	-	-	-	0.338
Kirkpatrick et al.	2006	-	-	-	-	-	-
Martins et al.	2006	-	-	-	1.747	0.455	-
Shih et al.	2006	-	-	-	-	-	-

Authors	Year of Publication	Economies of output density	Economies of customer density	Economies of spatial/network density	Economies of scale	Economies of Scope	Economies of Vertical Integration
Torres and Paul	2006	1.72	0.94	1.35	0.81	0.45	-
Aubert and Reynaud	2005	2.095 to 2.345	2.084 to 2.263	-	1.367 (short-run); 1.071 (long-run)	-	-
Fraquelli and Moiso	2005	1.87 to 18.53	-	-	0.65 to 2.18	-	-
Garcia-Valiñas	2005	-	-	-	-	-	-
Garcia-Valiñas	2005	-	-	-	-	-	-
Lin	2005	-	-	-	-	-	-
Sauer	2005	-	-	-	2.088 (short-run); 2.087 (long-run)	-	-
Urakami	2005	-	-	-	1.083: bulkwater only utilities; 1.108: retail utilities with own intake sources and distribution; 1.104: retail utilities buying water from bulk operators	-	-
Fraquelli et al.	2004	-	-	-	1.103 (global); 1.009 (water)	0.124 (global); 0.144 (water-gas); 0.045 (water-electricity)	-
Garcia and Reynaud	2004	1.377	-	-	1.019	-	-
Kirshen et al.	2004	-	-	-	-	-	-
Piacenza and Vannoni	2004	-	-	-	0.938 to 1.296	-0.753 to 0.639	-
Saal and Reid	2004	-	-	-	-	-	-

Authors	Year of Publication	Economies of output density	Economies of customer density	Economies of spatial/network density	Economies of scale	Economies of Scope	Economies of Vertical Integration
Stone & Webster Consultants	2004	-	-	-	Short-run: 0.67 to 1.01 (water and sewerage companies); 1.04 to 1.42 (water only companies). Long-run: 0.62 to 0.93 (water and sewerage companies); 0.98 to 1.25 (water only companies).	-	-
Urakami	2004	-	-	-	1.104	-	-
Ashton	2003	-	-	-	0.9633	-	-
Bottasso and Conti	2003	-	-	-	-	-	-
Corton	2003	-	-	-	-	-	-
Fraquelli and Giandrone	2003	-	-	-	1.23	-	-
Garcia and Thomas	2003	-	-	-	-	-	-
Estache and Rossi	2002	-	-	-	-	-	-
Antonioli and Filippini	2001	1.46	1.16	-	0.95	-	-
Garcia and Thomas	2001	1.21 (long-run); 1.14 (short-run)	0.87 (long-run); 1.05 (short-run)	-	1.0572	0.2367	-

Authors	Year of Publication	Economies of output density	Economies of customer density	Economies of spatial/network density	Economies of scale	Economies of Scope	Economies of Vertical Integration
Mizutani and Urakami	2001	1.095 to 1.131	-	1.10	0.895 to 0.921	-	-
Ashton	2000	-	-	-	-	-	-
Ashton	2000	-	-	-	1.475	-	-
Fabbri and Fraquelli	2000	1.09 to 1.58	-	-	0.99 to 1.014	-	-
Saal and Parker	2000	-	-	-	0.83 to 0.88	-	-
Renzetti	1999	-	-	-	1.249 (residential); 1.465 (non-residential); 1.364 (sewage treatment)	-	-
Cubbin and Tzanidakis	1998	-	-	-	-	-	-
Bhattacharyya et al.	1995	0.932 (public) to 1.246 (private)	-	-	-	-	-
Bhattacharyya et al.	1995	-	-	0.99	-	-	-
Hunt and Lynk	1995	-	-	-	-	-	-
Kim	1995	-	-	1.26	0.992	-	-
Bhattacharyya et al.	1994	-	-	-	-	-	-
Lynk	1993	-	-	-	-	-	-
Price	1993	-	-	-	-	-	-
Raffiee et al.	1993	-	-	-	-	-	-

Authors	Year of Publication	Economies of output density	Economies of customer density	Economies of spatial/network density	Economies of scale	Economies of Scope	Economies of Vertical Integration
Renzetti	1992	-	-	-	-	-	-
Male et al.	1991	-	-	-	1.02	-	-
Kim and Clark	1988	-	-	0.992	0.992	0.166	-
Hayes	1987	-	-	-	0.9506 to 1.9013	-0.1237 to 0.4723	-
Kim	1987	-	-	-	0.992	-	-
Teeples and Glyer	1987	-	-	-	-	-	-
Teeples and Glyer	1987	-	-	-	-	-	-
Fraas and Munley	1984	-	-	-	-	-	-
Feigenbaum and Teeples	1983	-	-	-	-	-	-
Clark and Stevie	1981	-	-	-	-	-	-
Crain and Zardkoohi	1978	-	-	-	1.28 (1.316 for public and 1.158 for private utilities)	-	-

Authors	Year of Publication	Economies of output density	Economies of customer density	Economies of spatial/network density	Economies of scale	Economies of Scope	Economies of Vertical Integration
Knapp	1978	-	-	-	-	-	-
Ford and Warford	1969	-	-	-	-	-	-
Hines	1969	-	-	-	-	-	-

Bibliography

Acharya, G. and Barbier, E. (2002), 'Using domestic water analysis to value groundwater recharge in the hadejia-jamaŠare floodplain, northern nigeria', *American Journal of Agricultural Economics* **84**(2), 415–426.

Agthe, D. E. and Billings, R. B. (1980), 'Dynamic models of residential water demand', *Water Resources Research* **16**(3), 476–480.

Agthe, D. E. and Billings, R. B. (1987), 'Equity, price elasticity and household income under increasing block rates for water', *American Journal of Economics and Sociology* **46**(3), 273–286.

Agthe, D. E. and Billings, R. B. (1997), 'Equity and conservation pricing policy for a government-run water utility', *Journal of Water Supply Research and Technology - AQUA* **46**(5), 252–260.

Agthe, D. E. and Billings, R. B. (2002), 'Water price influence on apartment complex water use', *Journal of Water Resources Planning and Management* **128**(5), 366–369.

Agthe, D. E. and Billings, R. B. (2003), Price rationing, *in* D. E. Agthe, R. B. Billings and N. Buras, eds, 'Managing Urban Water Supply', Kluwer Academic Publishers, Dordrecht, The Netherlands, chapter 3, pp. 23–43.

Agthe, D. E., Billings, R. B. and Buras, N. (2003), *Managing Urban Water Supply*, Kluwer Academic Publishers, Dordrecht, The Netherlands.

Agthe, D. E., Billings, R. B., Dobra, J. L. and Raffiee, K. (1986), 'A simultaneous equation demand model for block rates', *Water Resources Research* **22**(1), 1–4.

Al-Qunaibet, M. H. and Johnston, R. S. (1985), 'Municipal demand for water in kuwait: Methodological issues and empirical results', *Water Resources Research* **21**(4), 433–438.

Allais, M. (1947), 'Le problème de la coordination des transports et la théorie economique', *Revue d'Économie Politique* **58**, 212–271.

Alves, A. and Pinto, B., eds (2004), *Economia Da Água Do Plano Nacional Da Água*, INAG - Instituto da Água, Lisboa, Portugal.

Andrade, T. A., Brandão, A. S. P., de Araujo Lobão, W. J. and Silva, S. L. Q. D. (1995), 'Saneamento urbano: A demanda residencial por água', *Pesquisa e Planejamento Econômico* **25**(3), 427–448.

Andrews, D. R. and Gibbs, K. C. (1975), 'An analysis of the effect of price on residential water demand: Metropolitan miami, florida', *Southern Journal of Agricultural Economics* **7**(1), 125–30.

Antonioli, B. and Filippini, M. (2001), 'The use of a variable cost function in the regulation of the italian water industry', *Utilities Policy* **10**(3-4), 181–187.

APA/MAOTDR (2008), Relatórios do estado do ambiente e do ordenamento do território em portugal 20 anos, Technical report, Agência Portuguesa do Ambiente, Ministério do Ambiente, do Ordenamento do Território e do Desenvolvimento Regional, Amadora, Portugal.

APDA (2004), *Abastecimento de Água Em Portugal - O Mercado e Os Preços*, APDA - Associação Portuguesa de Distribuição e Drenagem de Águas, com o patrocínio do IRAR - Instituto Regulador de Águas e Resíduos, Lisboa, Portugal. Comissão Especializada de Legislação e Economia.

APDA (2006), *Água e Saneamento Em Portugal - O Mercado e Os Preços*, APDA - Associação Portuguesa de Distribuição e Drenagem de Águas, com o patrocínio do IRAR - Instituto Regulador de Águas e Resíduos, Lisboa, Portugal. Comissão Especializada de Legislação e Economia.

AR (2005), 'Law n. 58/2005 of december 29 (water law)', Diário da República, n. 249 Série I-A, 2005-12-29. Assembleia da República.

AR (2007), 'Law n. 2/2007 of january 15 (Local/Municipal finance law)', Diário da República, 1. série, n.10, 2007-01-15. Assembleia da República.

AR (2008), 'Law n. 12/2008 of february 26 (legislation regarding the protection of the customers of essential public services)'. Assembleia da República.

Arbués, F., Barberán, R. and Villanúa, I. (2004), 'Price impact on urban residential water demand: A dynamic panel data approach', *Water Resources Research* **40**(11), W11402(1)–W11402(9).

Arbués, F., García-Valiñas, M. A. and Martínez-Espiñeira, R. (2003), 'Estimation of residential water demand: A state-of-the-art review', *Journal of Socio-Economics* **32**, 81–102.

Arbués, F. and Villanúa, I. (2006), 'Potential for pricing policies in water resource management: Estimation of urban residential water demand in zaragoza, spain', *Urban Studies* **43**(13), 2421–2442.

Arbués-Gracia, F., Ortí, R. B. and Martín, I. V. (2008), Tamaño de los hogares y demanda de agua residencial: Una aproximación empírica, Technical report. Paper presented at the 3rd AERNA Congress, Palma de Mallorca, Spain, 4-6 June, 2008.

Arnell, N. W. (2004), 'Climate change and global water resources: SRES emissions and socio-economic scenarios', *Global Environmental Change* **14**(1), 31–52.

Ashton, J. K. (2000*a*), 'Cost efficiency in the UK water and sewerage industry', *Applied Economics Letters* **7**, 455–458.

Ashton, J. K. (2000*b*), 'Total factor productivity growth and technical change in the water and sewerage industry', *The Service Industries Journal* **20**(4), 121–130.

Ashton, J. K. (2003), 'Capital utilisation and scale in the english and welsh water industry', *The Service Industries Journal* **23**(5), 137–149.

Attanasi, E., Close, E. R. and Lopez, M. A. (1975), Techniques for water demand analysis and forecasting: Puerto rico, a case study, Report 75-94, United States Department of Interior, Geological Survey, Washington DC, USA.

Aubert, C. and Reynaud, A. (2005), 'The impact of regulation on cost efficiency: An empirical analysis of wisconsin water utilities', *Journal of Productivity Analysis* **23**(3), 383–409.

Ayadi, M., Krishnakumar, J. and Matoussi, M. S. (2003), A panel data analysis of residential water demand in presence of nonlinear progressive tariffs, Working paper presented at the 10th annual conference of the economic research forum, held in marrakesh, morocco in december 2003, Economic Research Forum.

Azomahou, T. (2008), 'Minimum distance estimation of the spatial panel autoregressive model', *Cliometrica* **2**(1), 1863–2505.

Babel, M. S., Das-Gupta, A. and Pradhan, P. (2007), 'A multivariate econometric approach for domestic water demand modeling: An application to kathmandu, nepal', *Water Resources Management* **21**(3), 573–589.

Bachrach, M. and Vaughan, W. J. (1994), Household water demand estimation, Working Paper ENP 106, Inter-American Development Bank, Productive Sectors and Environment Subdepartment, Environment Protection Division, Washington D.C., USA.

Bain, J., Caves, R. E. and Margolis, J. (1966), *Northern California's Water Industry: The Comparative Efficiency of Public Enterprise in Developing a Scarce Natural Resource*, Johns Hopkins Press, Baltimore, Maryland, USA.

Bakker, K. J. (2001), 'Paying for water: Water pricing and equity in england and wales', *Transactions of the Institute of British Geographers, New Series* **26**(2), 143–164.

Baltagi, B. H. and Wu, P. X. (1999), 'Unequally spaced panel data regressions with AR(1) disturbances', *Econometric Theory* **15**(6), 814–823.

Baptista, J. M., Pássaro, D. Á. and Santos, R. F. (2003), The regulation of the water and waste sectors in portugal, Technical report, IRAR - Instituto Regulador de Águas e Resíduos, Lisboa, Portugal.

Barberán, R. and Arbués, F. (2009), 'Equity in domestic water rates design', *Water Resources Management* **23**(10), 2101–2118.

Barkatullah, N. (1996), OLS and instrumental variable price elasticity estimates for water in mixed-effects model under multiple tariff structure, Working Papers in Economics 226, University of Sydney, Department of Economics, Sydney, Australia.

Barrett, R. and Sinclair, P. (1999), Water charges and the cost of metering, Discussion Paper 99-05, University of Birmingham, Department of Economics, Birmingham, UK.

Bartczak, A., Kopanska, A. and Raczka, J. (2009), Residential water demand in a transition economy: Evidence from poland, Working paper, Warsaw Ecological Economics Center, Warsaw University, Warsaw, Poland.

Bartoszczuk, P. and Nakamori, Y. (2004), Modeling sustainable water prices, *in* M. Quaddus and A. Siddique, eds, 'Handbook of Sustainable Development Planning: Studies in Modelling and Decision Support', Edward Elgar Publishers, Cheltenham, UK, chapter 10.

Basania, M., Ishamb, J. and Reilly, B. (2008), 'The determinants of water connection and water consumption: Empirical evidence from a cambodian household survey', *World Development* **36**(5), 953–968.

Batchelor, R. A. (1975), 'Household technology and the domestic demand for water', *Land Economics* **5**(3), 208–223.

Bates, B., Kundzewicz, Z., Wu, S. and Palutikof, J., eds (2008), *Climate Change and Water*, Technical Paper IV, Intergovernmental Panel on Climate Change, Geneva, Switzerland.

Baum, C. F. and Stillman, S. (1999), 'DMEXOGXT: Stata module to test consistency of OLS vs XT-IV estimates', Available at http://ideas.repec.org/c/boc/bocode/s401103.html.

Baumann, D. D., Boland, J. J. and Hanemann, W. M. (1997), *Urban Water Demand Management and Planning*, McGraw-Hill, New York, USA.

Beare, S. C., Bell, R. and Fischer, B. S. (1998), 'Determining the value of water: The role of risk, infrastructure constraints, and ownership', *American Journal of Agricultural Economics* **80**(5), 916–940.

Bell, D. R. and Griffin, R. C. (2008), 'An annual quasidifference approach to water price elasticity', *Water Resources Research* **44**, W08420 (1–9).

Ben-Zvi, S. (1980), Estimates of price and income elasticities of demand for water in industrial use in the red river basin, Technical report, U.S. Army Corps of Engineers, Tulsa, Oklahoma, USA.

Bhattacharyya, A., Harris, T. R., Narayanan, R. and Raffiee, K. (1995), 'Allocative efficiency of rural nevada water systems: A hedonic shadow cost function approach', *Journal of Regional Science* **35**(3), 485–502.

Bhattacharyya, A., Harris, T. R., Narayanana, R. and Raffiee, K. (1995), 'Specification and estimation of the effect of ownership on the economic efficiency of the water utilities', *Regional Science and Urban Economics* **25**(6), 759–784.

Bhattacharyya, A., Parker, E. and Raffiee, K. (1994), 'An examination of the effect of ownership on the relative efficiency of public and private water utilites', *Land Economics* **70**(2), 197–209.

Billings, B. R. (1990), 'Demand-based benefit cost model of participation in water project', *Journal of Water Resources Planning and Management* **116**(5), 593–609.

Billings, R. B. (1982), 'Specification of block rate price variables in demand models', *Land Economics* **58**(3), 386–394.

Billings, R. B. (1987), 'Alternative demand model estimators for block rate pricing', *Water Resources Bulletin* **23**(2), 341–345.

Billings, R. B. and Agthe, D. E. (1980), 'Price elasticities for water: A case of increasing block rates', *Land Economics* **56**(1), 73–84.

Billings, R. B. and Agthe, D. E. (1998), 'State-space versus multiple regression for forecasting urban water demand', *Journal of Water Resources Planning and Management - ASCE* **124**(2), 113–117.

Billings, R. B. and Day, W. M. (1989), 'Demand management factors in residential water use: The southern arizona experience', *Journal of the American Water Works Association* **81**(3), 58–64.

Bithas, K. (2008), 'The sustainable residential water use: Sustainability, efficiency and social equity. the european experience', *Ecological Economics* **68**(1), 221–229.

Boistard, P. (1993), 'Influence of the price of public water utilities on domestic water consumption', *Revue des Sciences de l'Eau (Journal of Water Science)* **6**(3), 335–352.

Boiteux, M. (1949), 'La tarification des demandes en pointe', *Revue Générale de l'Électricité* **58**, 321–340. Translated as "Peak-load pricing", Journal of Business 33(2) (1960): 157-179.

Boland, J. J., Dziegielewski, B., Baumann, D. D. and Optiz, E. M. (1984), Influence of price and rate structures on municipal and industrial water use, Contract report 84-c-2, U.S. Army Corps of Engineers, Institute for Water Resources, Ft. Belvoir, Va., USA.

Boland, J. J. and Whittington, D. (2000), The political economy of water tariff design in developing countries: Increasing block tariffs versus uniform price with rebate, *in* A. Dinar, ed., 'The Political Economy of Water Pricing Reforms', Oxford University Press, New York, USA, chapter 10, pp. 215–235.

Bottasso, A. and Conti, M. (2003), Cost inefficiency in the english and welsh water industry: An heteroskedastic stochastic cost frontier approach, Economics Discussion Papers 573, University of Essex, Department of Economics, Essex, UK.

Bottasso, A. and Conti, M. (2009), 'Scale economies, technology and technical change in the water industry: Evidence from the english water only sector', *Regional Science and Urban Economics* **39**(2), 138–147.

Bouscasse, H., Destandau, F. and Garcia, S. (2008), 'Analyse économétrique des coûts des services d'eau potable et qualité des prestations offertes aux usagers', *Revue d'économie industrielle* **122**(2), 7–26.

Briand, A. (2006), Marginal cost versus average cost pricing with climatic shocks in senegal: A dynamic computable general equilibrium model applied to water, Working Paper 144.06, FEEM - Fondazione Eni Enrico Mattei, Milano, Italy.

Brill, E., Hochman, E. and Zilberman, D. (1997), 'Allocation and pricing at the water district level', *American Journal of Agricultural Economics* **79**(3), 952–963.

Brock, W. A. and Dechert, W. D. (1985), 'Dynamic ramsey pricing', *International Economic Review* **26**(3), 569–591.

Brown, G. and McGuire, C. B. (1967), 'A socially optimal pricing policy for a public water agency', *Water Resources Research* **3**(1), 33–43.

Brown, S. and Sibley, D. (1986), *The Theory of Public Utility Pricing*, Cambridge University Press, Cambridge, UK.

Cabral, L. M. B. (2000), *Introduction to Industrial Organization*, The MIT Press, Cambridge, Massachusetts, USA; London, UK.

Camp, R. C. (1978), 'The inelastic demand for residential water: New findings', *Journal of the American Water Works Association* **70**(8), 452–458.

Cardadeiro, E. (2005), Regulação Económica Da Indústria de Abastecimento de Água e Saneamento, PhD thesis, University of Évora, Évora, Portugal. PhD supervisors: Aníbal Santos and Amado da Silva.

Carter, D. W. and Milon, J. W. (2005), 'Price knowledge in household demand for utility services', *Land Economics* **81**(2), 265–283.

Carver, P. H. and Boland, J. (1980), 'Short- and long-run effects of price on municipal water use', *Water Resources Research* **16**(4), 609–616.

Cassuto, A. E. and Ryan, S. (1979), 'Effect of price on the residential demand for water within an agency', *Water Resources Bulletin* **15**(2), 345–353.

Castro-Rodríguez, Fidel, J. M. D.-R. and Delicado, P. (2002), 'Desperately seeking theta 's: Estimating the distribution of consumers under increasing block rates', *Journal of Regulatory Economics* **22**(1), 29–58.

Chambouleyron, A. (2004), 'Optimal water metering and pricing', *Water Resources Management* **18**(4), 305–319.

Cheesman, J., Bennett, J. and Son, T. V. H. (2008), 'Estimating household water demand using revealed and contingent behaviors: Evidence from vietnam', *Water Resources Research* **44**(11), W11428 (1–11).

Chicoine, D. L., Deller, S. C. and Ramamurthy, G. (1986), 'Water demand estimation under block rate pricing: A simultaneous equation approach', *Water Resources Research* **22**(6), 859–863.

Chicoine, D. L. and Ramamurthy, G. (1986), 'Evidence on the specification of price in the study of domestic water demand', *Land Economics* **62**(1), 26–32.

Christensen, L. R., Jorgenson, D. W. and Lau, L. J. (1971), 'Conjugate duality and the transcendental logarithmic production function', *Econometrica* **39**(4), 255–256.

Clark, R. M. (1976), 'Cost and pricing relationships in water supply', *Journal of the Environmental Engineering Division* **102**(2), 361–373.

Clark, R. M. and Stevie, R. G. (1981*a*), 'A regional water supply cost model', *Growth and Change* **12**(3), 9–16.

Clark, R. M. and Stevie, R. G. (1981*b*), 'A water supply cost model incorporating spatial variables', *Land Economics* **57**(1), 18–32.

Coase, R. (1946), 'The marginal cost controversy', *Economica* **13**(51), 169–182.

Coase, R. (1970), 'The theory of public utility pricing and its application', *Bell Journal of Economics and Management Science* **1**(1), 113–128.

COBA-PROCESL (2007), National programs of dams with high hydroelectric potential (PNBEPH), Technical report, INAG - National Water Institute, Directorate-General of Energy and Geology and REN - National Energy Networks.

Cochran, R. and Cotton, A. W. (1985), 'Municipal water demand study, oklahoma city and tulsa, oklahoma', *Water Resources Research* **21**(7), 941–943.

Colander, D. C. and Haltiwanger, J. C. (1979), 'Comment on 'price elasticity of demand for municipal water: A case study of tucson, arizona' by robert a. young', *Water Resources Research* **15**(5), 1275–1277.

Collinge, R. A. (1992), 'Revenue neutral water conservation: Marginal cost pricing with discount coupons', *Water Resources Research* **28**(3), 617–622.

Conley, B. C. (1967), 'Price elasticity of demand for water in southern california', *Annals of Regional Science* **1**(1), 180–189.

Corral, L. R., Fisher, A. C. and Hatch, N. W. (1999), Price and non-price influences on water conservation: An econometric model of aggregate demand under nonlinear budget constraint, CUDARE Working Papers 881, Department of Agricultural and Resource Economics and Policy, University of California at Berkeley, Berkeley, California, USA.

Corton, M. L. (2003), 'Benchmarking in the latin american water sector: The case of peru', *Utilities Policy* **11**(3), 133–142.

Crain, W. M. and Zardkoohi, A. (1978), 'A test of the property-rights theory of the firm: Water utilities in the united states', *Journal of Law and Economics* **21**(2), 395–408.

Crane, R. (1994), 'Water markets, market reform and the urban poor: Results from jakarta, indonesia', *World Development* **22**(1), 71–83.

Crase, L., O'Keefe, S. and Burston, J. (2007), 'Inclining block tariffs for urban water', *Agenda* **14**(1), 69–80.

Cubbin, J. and Tzanidakis, G. (1998), 'Regression versus data envelopment analysis for efficiency measurement: An application to the england and wales regulated water industry', *Utilities Policy* **7**(2), 75–85.

Cunha, L. V. D., Oliveira, R. and Nunes, V. (2002), Water resources, *in* F. D. Santos, K. Forbes and R. Moita, eds, 'Climate Change in Portugal. Scenarios, Impacts and Adaptation Measures - SIAM Project', Gradiva, Lisboa, Portugal, chapter 5, pp. 133–171.

Dahan, M. and Nisan, U. (2007), 'Unintended consequences of increasing block tariffs pricing policy in urban water', *Water Resources Research* **43**(3), 1–10.

Dalhuisen, J., Groot, H. and Nijkamp, P. (2001), Thematic report on the economics of water in metropolitan areas, Technical report, European Commission: Environment and Climate Programme, Metropolitan Areas and Sustainable Use of Water.

Dalhuisen, J. M., Florax, R. J. G. M., de Groot, H. L. F. and Nijkamp, P. (2003), 'Price and income elasticities of residential water demand: A meta-analysis', *Land Economics* **79**(2), 292–308.

Dalmas, L. and Reynaud, A. (2005), Residential water demand in the slovak republic, *in* P. Koundouri, ed., 'Econometrics Informing Natural Resources Management: Selected Empirical Analyses', Edward Elgar Publishing, Cheltenham, UK, chapter 4, pp. 83–109.

Dandy, G. C., McBean, E. A. and Hutchinson, B. G. (1984), 'A model for constrained optimum water pricing and capacity expansion', *Water Resources Research* **20**(5), 511–520.

Dandy, G. C., Nguyen, T. and Davies, C. (1997), 'Estimating residential water demand in the presence of free allowances', *Land Economics* **73**(1), 125–139.

Danielson, L. E. (1979), 'An analysis of residential demand for water using micro time-series data', *Water Resources Research* **15**(4), 763–67.

Darr, P., Feldman, S. L. and Kamen, C. S. (1975), 'Socioeconomic factors affecting domestic water demand in israel', *Water Resources Research* **11**(6), 805–809.

David, C. C. and Inocencio, A. B. (1998), Understanding household demand for water: The metro manila case, Technical report, Economy and Environment Program for Southeast Asia, Singapore.

Davidson, R. and MacKinnon, J. (1993), *Estimation and Inference in Econometrics*, Oxford University Press, New York, USA.

Davidson, R. and MacKinnon, J. G. (1981), 'Several tests for model specification in the presence of alternative hypothesis', *Econometrica* **49**(3), 781–793.

de Barros Mattos, Z. P. (1998), 'Uma análise da demanda residencial por água usando diferentes métodos de estimação', *Pesquisa e Planejamento Econômico* **28**(1), 207–223.

Decaluwé, B., Patry, A. and Savard, L. (1999), When water is no longer heaven sent: Comparative pricing analysis in an AGE model, Working Paper 99-05, CREFA - Centre de Recherche en Économie et Finance Appliquées, Département dŠéconomique, Université Laval, Montréal, Canada.

Deller, S. C., Chicoine, D. and Ramamurthy, G. (1986), 'Instrumental variables approach to rural water service demand', *Southern Economic Journal* **53**(2), 333–346.

Diakité, D., Semenov, A. and Thomas, A. (2009), 'A proposal for social pricing of water supply in côte d'Ivoire', *Journal of Development Economics* **88**(2), 258–268.

Dixon, P. B. (1990), 'A general equilibrium approach to public utility pricing: Determining prices for a water authority', *Journal of Policy Modeling* **12**(4), 745–767.

Dupuit, A. J. E. (1844), 'De la mesure de l'utilité des travaux publics', *Annales des Ponts et Chausées* **2**, 332–375. Translated as "On the measurement of the utility of public works", International Economic Papers 2: 256-283.

Dziegielewski, B. (1996), Long term forecasting of urban water demands, *in* D. C. Hall, ed., 'Marginal Cost Rate Design and Wholesale Water Markets', Vol. 1 of *Advances in the Economics of Environmental Resources*, Jai Press Inc., Greenwich, Connecticut, USA, pp. 33–47.

Dzisiak, R. N. (1999), The Role of Price in Determining Residential Water Demand, Water Pricing and Residential Water Demand in Municipalities in the Western Prairies, PhD thesis, University of Manitoba, Faculty of Graduate Studies, Department of Agricultural Economics, Winnipeg, Canada. M.Sc. Thesis.

EAGCP (2006), 'Services of general economic interest'. Opinion Prepared by the State Aid Group of EAGCP - Economic Advisory Group on Competition Policy, Directorate General of Competition, European Commission.

EC (2003), Green paper on services of general interest, Communication from the European Commission COM(2003) 270 final, European Commission, Brussels, Belgium.

EC (2004), White paper on services of general interest, Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions COM(2004) 374 final, European Commission, Brussels, Belgium.

EC (2006), Water scarcity and drought - in depth assessment: First interim report, Technical report, European Commission, Brussels, Belgium.

EC (2007*a*), Addressing the challenge of water scarcity and droughts in the european union, Communication from the Commission to the European Parliament and the Council COM(2007) 414 final, European Commission, Brussels, Belgium.

EC (2007*b*), Services of general interest, including social services of general interest: A new european commitment, Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions COM(2007) 725 final, European Commission, Brussels, Belgium.

EC (2007*c*), Water scarcity and drought: Second interim report, Technical report, European Commission, DG Environment, Brussels, Belgium.

EC (2008*a*), Drought management plan report - including agricultural, drought indicators and climate change aspects, Technical Report 2008-023, European Commission - Water Scarcity and Droughts Expert Network, Luxembourg.

EC (2008*b*), Guide to cost-benefit analysis of investment projects: Structural funds, cohesion fund and instrument for pre-accession, Technical report, Directorate General Regional Policy, European Commission, Brussels, Belgium.

EEA (2007*a*), Climate change and water adaptation issues (technical report 2), Technical Report 02/2007, European Environmental Agency, Copenhagen, Denmark.

EEA (2007*b*), Europe's environment - the fourth assessment, State of the environment report 1/2007, European Environmental Agency, Copenhagen, Denmark.

EEA (2008), Impacts of europe's changing climate - 2008 indicator-based assessment, Report 04/2008, European Environmental Agency, Copenhagen, Denmark.

EEA (2009), Water resources across europe - confronting water scarcity and drought, EEA Report 2/2009, European Environment Agency, Copenhagen, Denmark.

Elnaboulsi, J. C. (2001), 'Nonlinear pricing and capacity planning for water and wastewater services', *Water Resources Management* **15**(1), 55–69.

Elnaboulsi, J. C. (2009), 'An incentive water pricing policy for sustainable water use', *Environmental and Resource Economics* **42**(4), 451–469.

Embid-Irujo, A. (2005), 'Water pricing in spain', *International Journal of Water Resources Development* **21**(1), 31–41.

Espey, M., Espey, J. and Shaw, W. D. (1997), 'Price elasticity of residential demand for water: A meta-analysis', *Water Resources Research* **33**(6), 1369–1374.

Estache, A. and Rossi, M. A. (2002), 'How different is the efficiency of public and private water companies in asia?', *The World Bank Economic Review* **16**(1), 139–148.

EU (2000), 'Directive 2000/60/EC of the european parliament and of the council establishing a framework for the community action in the field of water policy - EU water framework directive', Official Journal (OJ L 327).

EU (2007), '2007/c 306/01 treaty of lisbon amending the treaty on european union and the treaty establishing the european community, signed at lisbon, 13 december 2007', Official Journal (OJ C 306).

Evans, D. J. and Sezer, H. (2005), 'Social discount rates for member countries of the european union', *Journal of Economic Studies* **32**(1), 47–59.

Fabbri, P. and Fraquelli, G. (2000), 'Costs and structure of technology in the italian water industry', *Empirica* **27**(1), 65–82.

Fankhauser, S. and Tepic, S. (2005), Can poor consumers pay for energy and water? an affordability analysis for transition countries, Working Paper 92, European Bank for Reconstruction and Development, London, UK.

Farsi, M., Fetz, A. and Filippini, M. (2008), 'Economies of scale and scope in multi-utilities', *Energy Journal* **29**(4), 123–143.

Farsi, M. and Filippini, M. (2009), 'An analysis of cost efficiency in swiss multi-utilities', *Energy Economics* **31**(2), 306–315.

Feigenbaum, S. and Teeples, R. (1983), 'Public versus private water delivery: A hedonic cost approach', *Review of Economics and Statistics* **65**(4), 672–678.

Feldstein, M. (1972), 'Equity and efficiency in public sector pricing: The optimal two-part tariff', *Quarterly Journal of Economics* **86**(2), 175–187.

Filippini, M., Hrovatin, N. and Zoric, J. (2008), 'Cost efficiency of slovenian water distribution utilities: An application of stochastic frontier methods', *Journal of Productivity Analysis* **29**(2), 169–182.

Finger, M., Allouche, J. and Luis-Manso, P. (2007), *Water and Liberalisation: European Water Scenarios*, IWA Publishing, London, UK.

Flack, J. E. (1965), Water Rights Transfers - An Engineering Approach, Phd thesis, Stanford University, Palo Alto, California, USA.

Ford, J. L. and Warford, J. J. (1969), 'Cost functions for the water industry', *Journal of Industrial Economics* **18**(11), 53–63.

Ford, R. K. and Ziegler, J. A. (1981), 'Intrastate differences in residential water demand', *The Annals of Regional Science* **15**(3), 20–30.

Foster, H. S. and Beattie, B. R. (1979), 'Urban residential demand for water in the united states', *Land Economics* **55**(1), 43–58.

Foster, H. S. and Beattie, B. R. (1981), 'On the specification of price in studies of consumer demand under block price schedulling', *Land Economics* **57**(4), 624–629.

Foster, V. and Yepes, T. (2006), Is cost recovery a feasible objective for water and electricity? the latin american experience, Policy Research Working Paper Series 3943, The World Bank, Washington, D. C., USA.

Fourt, L. (1958), Forecasting the urban residential demand for water, Unpublished paper, Agricultural Economics Seminar, University of Chicago, Chicago, Illinois, USA.

Fraas, A. G. and Munley, V. G. (1984), 'Municipal wastewater treatment cost', *Journal of Environmental Economics and Management* **11**(1), 28–38.

Fraquelli, G. and Giandrone, R. (2003), 'Reforming the wastewater treatment sector in italy: Implications of plant size, structure, and scale economies', *Water Resources Research* **39**(10), WES1–WES7.

Fraquelli, G. and Moiso, V. (2005), Cost efficiency and economies of scale in the italian water industry, Working Paper 8/2005, HERMES - Higher Education on Research and Mobility Regulation and the Economics of Local Services, Torino, Italy.

Fraquelli, G., Piacenza, M. and Vannoni, D. (2004), 'Scope and scale economies in multi-utilities: Evidence from gas, water and electricity combinations', *Applied Economics* **36**(18), 2045–2057.

Freedman, D. A. (1986), 'A model for water pricing', *Journal of Business and Economic Statistics* **4**(1), 131–133.

Frerichs, S., Becker, N. and Easter, K. W. (1987), Alternative price specification for municipal water demands: An empirical test, Economic Reports 13033, University of Minnesota, Department of Applied Economics, St. Paul, Minnesota, USA.

Frondel, M. and Messner, F. (2008), Price perception and residential water demand: Evidence from a german household panel, Technical report. Poster presented at the EAERE 2008 held in Gotemburg, Sweden.

Fullerton-Jr, T. M., Tinajero, R. and Cota, J. E. M. (2007), 'An empirical analysis of tijuana water consumption', *Atlantic Economic Journal* **35**(3), 357–369.

Fullerton, T. M. and Elías, A. (2004), 'Short-term water consumption dynamics in el paso, texas', *Water Resources Research* **40**(8), W08201.1–W08201.7.

Fullerton, T. M. and Nava, A. C. (2003), 'Short-term water dynamics in chihuahua city, mexico', *Water Resources Research* **39**(9), WES1.1–WES1.6.

Fullerton, T. M., Tinajero, R. and Anda, M. P. B. (2006), 'Short-term water consumption patterns in ciudad juárez, mexico', *Atlantic Economic Journal* **34**(4), 467–479.

Garcia, S., Moreaux, M. and Reynaud, A. (2007), 'Measuring economies of vertical integration in network industries: An application to the water sector', *International Journal of Industrial Organization* **25**(4), 791–820.

Garcia, S. and Reynaud, A. (2004), 'Estimating the benefits of efficient water pricing in france', *Resource and Energy Economics* **26**(1), 1–25.

Garcia, S. and Thomas, A. (2001), 'The structure of municipal water supply costs: Application to a panel of french local communities', *Journal of Productivity Analysis* **16**(1), 5–29.

Garcia, S. and Thomas, A. (2003), 'Regulation of public utilities under asymmetric information: The case of municipal water supply in france', *Environmental and Resource Economics* **26**(1), 145–162.

García-Valiñas, M. A. (2005*a*), 'Efficiency and equity in natural resources pricing: A proposal for urban water distribution service', *Environmental and Resource Economics* **32**(2), 183–204.

García-Valiñas, M. A. (2005*b*), Estimating urban water demands: A dynamic approach, *in* P. Kounduri, ed., 'Econometrics Informing Natural Resources Management: Selected Empirical Analyses (New Horizons in Environmental Economics)', Edward Elgar Publishing, Cheltenham, UK, chapter 5, pp. 110–123.

García-Valiñas, M. A. (2005*c*), 'Fijación de precios para el servicio municipal de suministro de agua: Un ejercicio de análisis de bienestar', *Hacienda Pública Española / Revista de Economía Pública* **172**(1), 119–142.

García-Valiñas, M. A. (2006), 'Analysing rationing policies: Droughts and its effects on urban users' welfare', *Applied Economics* **38**(8), 955–965.

García-Valiñas, M. A., Nauges, C. and Reynaud, A. (2009), How much water do residential users really need? an estimation of minimum water requirements for french households, Technical report. Paper presented at the 17th Annual Conference of EAERE - European Association of Environmental and Resource Economists, Amsterdam, 24-27 June.

Gardner, B. D. and Schick, S. H. (1964), Factors affecting consumption of urban household water in northern utah, Bulletin 449, Agricultural Experiment Station, Utah State University, Logan, Utah, USA.

Garrido, R. (2005), 'Price setting for water use charges in brazil', *International Journal of Water Resources Development* **21**(1), 99–117.

Gaudin, S. (2005), 'Using water bills to reinforce price signals: Evidence from the US', *Water Supply* **5**(6), 163–171.

Gaudin, S. (2006), 'Effect of price information on residential water demand', *Applied Economics* **38**(4), 383–393.

Gaudin, S., Griffin, R. C. and Sickles, R. C. (2001), 'Demand specification for municipal water management: Evaluation of the stone-geary form', *Land Economics* **77**(3), 399–422.

Gibbs, K. C. (1978), 'Price variable in residential water demand models', *Water Resources Research* **14**(2), 15–18.

Gómez-Ramos, A. and Garrido-Colmenero, A. (1998), El análisis de demanda de agua para usos urbanos: El estado de la cuestión y las áreas por explorar, Working paper presented at the i congreso ibérico sobre planificácion y gestión de águas (1st iberian congress on water planning and management) held in zaragoza, spain, in 14-18 september 1998, Iberian Congress on Water Planning and Management.

Gottlieb, M. (1963), 'Urban domestic demand of water: A kansas case study', *Land Economics* **39**(2), 204–210.

Grafton, R. Q. and Kompas, T. (2007), 'Pricing sydney water', *The Australian Journal of Agricultural and Resource Economics* **51**(3), 227–241.

Grafton, R. Q. and Ward, M. (2007), Prices versus rationing: Marshallian surplus and mandatory water restrictions, International and Development Economics Working Papers 07-05, Australian National University - Crawford School of Economics and Government, Canberra, Australia.

Greene, W. H. (2003), *Econometric Analysis*, 5th edn, Prentice-Hall, New Jersey, USA.

Griffin, A. H. and Martin, W. E. (1981), 'Price elasticities for water: A case of increasing block rates: Comment', *Land Economics* **57**(2), 266–275.

Griffin, A. H., Martin, W. E. and Wade, J. C. (1981), 'Urban residential demand for water in the united states: Comment', *Land Economics* **57**(2), 252–256.

Griffin, R. C. (2001), 'Effective water pricing', *Journal of the American Water Resources Association* **37**(5), 1335–1347.

Griffin, R. C. (2006), *Water Resource Economics: The Analysis of Scarcity, Policies, and Projects*, MIT Press, Cambridge, Massachusetts, USA.

Griffin, R. C. and Chang, C. (1990), 'Pretest analysis of water demand in thirty communities', *Water Resources Research* **26**(10), 2251–2255.

Griffin, R. C. and Chang, C. (1991), 'Seasonality in community water demand', *Western Journal of Agricultural Economics* **16**(2), 207–217.

Grima, A. P. L. (1973), 'The impact of policy variables on residential water demand and related investment requirements', *Water Resources Bulletin* **9**(4), 703–710.

Grunewald, O., Haan, C. T., Debertin, D. L. and Carey, D. I. (1976), 'Rural residential water demand: A econometric and simulation analysis', *Water Resources Bulletin* **12**(5), 951–961.

Gunatilake, H. M., Gopalakrishnanand, C. and Chandrasena, I. (2001), 'The economics of household demand for water: The case of kandy municipality, sri lanka', *International Journal of Water Resources Development* **17**(3), 277–288.

Gysi, M. and Loucks, D. P. (1971), 'Some long run effects of water-pricing policies', *Water Resources Research* **7**(6), 1371–1382.

Hajispyrou, S., Koundouri, P. and Pashardes, P. (2002), 'Household demand and welfare implications of water pricing in cyprus', *Environment and Development Economics* **7**(4), 659–685.

Hanemann, W. M. (1997*a*), Determinants of urban water use, *in* D. D. Baumann, J. J. Boland and W. M. Hanemann, eds, 'Urban Water Demand Management and Planning', McGraw-Hill, New York, USA, pp. 31–75. Chap. 2.

Hanemann, W. M. (1997*b*), Price and rate structures, *in* D. D. Baumann, J. J. Boland and W. M. Hanemann, eds, 'Urban Water Demand Management and Planning', McGraw-Hill, New York, USA, pp. 137–179. Chap. 5.

Hanemann, W. M. and Nauges, C. (2005), Heterogeneous responses to water conservation programs: The case of residential users in los angeles, CUDARE Working Papers 1026, Department of Agricultural and Resource Economics, University of California, Berkeley, Berkeley, California, USA.

Hanke, S. H. (1970), 'Demand for water under dynamic conditions', *Water Resources Research* **6**(5), 1253–1261.

Hanke, S. H. and Davis, R. K. (1971), 'Demand management through responsive pricing', *Journal of the American Water Works Association* **73**(9), 555–560.

Hanke, S. H. and de Maré, L. (1982), 'Residential water demand: A pooled time-series cross-section study of malmö, sweden', *Water Resources Bulletin* **18**(4), 621–625.

Hansen, L. G. (1996), 'Water and energy price impacts on residential water demand in copenhagen', *Land Economics* **72**(1), 66–79.

Hayes, K. (1987), 'Cost structure of the water utility industry', *Applied Economics* **19**(3), 417–425.

Headley, C. (1963), 'The relation of family income and use of water for residential and commercial purposes in the san francisco-oakland metropolitan area', *Land Economics* **39**(4), 441–449.

Hensher, D., Shore, N. and Train, K. (2005), 'Households' willingness to pay for water service attributes', *Environmental and Resource Economics* **32**(4), 509–531.

Hewitt, J. A. (2000), An investigation into the reasons why water utilities choose particular residential rate structures, *in* A. Dinar, ed., 'The Political Economy of Water Pricing Reforms', Oxford University Press, New York, USA, chapter 12, pp. 259–277.

Hewitt, J. A. and Hanemann, W. M. (1995), 'A Discrete/Continuous choice approach to residential water demand under block rate pricing', *Land Economics* **71**(2), 173–192.

Higgs, H. and Worthington, A. (2001), 'Consumer preferences and water charging options in a large urban municipality: A case study', *Public Works Management and Policy* **5**(3), 209–207.

Hines, L. G. (1969), 'The long run cost function of water production for selected wisconsin communities', *Land Economics* **45**(1), 133–140.

Hirshleifer, J., de Haven, J. C. and Milliman, J. W. (1960), *Water Supply: Economics, Technology and Policy*, University of Chicago Press, Chicago, Illinois, USA.

Hoffmann, M., Worthington, A. and Higgs, H. (2006), 'Urban water demand with fixed volumetric charging in a large municipality: The case of brisbane, australia', *Australian Journal of Agricultural and Resource Economics* **50**(3), 347–360.

Hogarty, T. F. and MacKay, R. J. (1975), 'The impact of large temporary rate changes on residential water use', *Water Resources Research* **11**(6), 791–794.

Höglund, L. (1999), 'Household demand for water in sweden with implications of a potential tax on water use', *Water Resources Research* **35**(12), 3853–3863.

Hotelling, H. (1931), 'The economics of exhaustible resources', *Journal of Political Economy* **39**, 137–175.

Howe, C. W. (1982), 'The impact of price on residential water demand: Some new insights', *Water Resources Research* **18**(4), 713–716.

Howe, C. W. (2005), 'The functions, impacts and effectiveness of water pricing: Evidence from the united states and canada', *International Journal of Water Resources Development* **21**(1), 43–53.

Howe, C. W. and Jr, F. P. L. (1967), 'The impact of price on residential water demand and its relation to system design and price structure', *Water Resources Research* **3**(1), 13–32.

Hunt, L. C. and Lynk, E. L. (1995), 'Privatisation and efficiency in the UK water industry: An empirical analysis', *Oxford Bulletin of Economics and Statistics* **57**(3), 371–388.

ICWE (1992), *The Dublin Statement on Water and Sustainable Development*, International Conference on Water and the Environment, Dublin, Ireland.

Iimi, A. (2008), (UN)Bundling public-private partnership contracts in the water sector: Competition in auctions and economies of scale in operation, Policy Research Working Paper 4459, The World Bank, Washington, D. C., USA.

INAG/MAOTDR (2005), Relatório síntese sobre a caracterização das regiões hidrográficas prevista na directiva quadro da água, Technical report, Instituto da Água, Ministério do Ambiente, do Ordenamento do Território e do Desenvolvimento Regional, Lisboa, Portugal.

INAG/MAOTDR (2007), Relatório sobre o estado dos sistemas públicos de abastecimento de água e de drenagem e tratamento de águas residuais - INSAAR 2005, Technical report, Instituto da Água, Ministério do Ambiente, do Ordenamento do Território e do Desenvolvimento Regional, Lisboa, Portugal.

INAG/MAOTDR (2008), Relatório do estado do abastecimento de água e de saneamento de águas residuais - campanha INSAAR 2006, Technical report, Instituto da Água, Ministério do Ambiente, do Ordenamento do Território e do Desenvolvimento Regional, Lisboa, Portugal.

INAG/MAOTDR (2009), Relatório do estado do abastecimento de água e drenagem e tratamento de águas residuais - sistemas públicos urbanos - INSAAR 2008, Technical report, Instituto da Água, Ministério do Ambiente, do Ordenamento do Território e do Desenvolvimento Regional, Lisboa, Portugal.

Ipe, V. C. and Bhagwat, S. B. (2002), 'Chicago's water market: Dynamics of demand, prices and scarcity rents', *Applied Economics* **34**(17), 2157–2163.

IRAR (2007), Relatório anual dos serviços de águas e resíduos em portugal - 2006, Technical report, IRAR - Instituto Regulador de Águas e Resíduos, Lisboa, Portugal.

IRAR (2008*a*), Nota sobre a nova legislação relativa a serviços públicos essenciais. [comment on the new legislation regarding essential public services], Technical report, IRAR - Instituto Regulador de Águas e Resíduos, Lisboa, Portugal.

IRAR (2008*b*), Relatório anual dos serviços de águas e resíduos em portugal - 2007, Technical report, IRAR - Instituto Regulador de Águas e Resíduos, Lisboa, Portugal.

IRAR/LNEC (2007), *Guia de Avaliação Da Qualidade Dos Serviços de Águas e Resíduos Prestados Aos Utilizadores, Versão 3.*, Instituto Regulador de Águas e Resíduos; Laboratório Nacional de Engenharia Civil, Lisboa, Portugal.

Jansen, A. and Schulz, C.-E. (2006), 'Water demand and the urban poor: A study of the factors influencing water consumption among households in cape town, south africa', *South African Journal of Economics* **74**(3), 593–609.

Jones, C. V. and Morris, J. R. (1984), 'Instrumental price estimates and residential water demand', *Water Resources Research* **20**(2), 197–202.

Katzman, M. T. (1977), 'Income and price elasticities of demand for water in developing countries', *Water Resources Bulletin* **13**(1), 47–55.

Kenney, D. S., Goemans, C., Klein, R., Lowrey, J. and Reidy, K. (2008), 'Residential water demand management: Lessons from aurora, colorado', *Journal of the American Water Resources Association* **44**(1), 192–207.

Kim, E. and Lee, H. (1998), 'Spatial integration of urban water services and economies of scale', *Review of Urban and Regional Development Studies* **10**(1), 3–18.

Kim, H. Y. (1987), 'Economies of scale in multi-product firms: An empirical analysis', *Economica* **54**(214), 185–206.

Kim, H. Y. (1995), 'Marginal cost and second-best pricing for water services', *Review of Industrial Organization* **10**(3), 323–338.

Kim, H. Y. and Clark, R. (1988), 'Economies of scale and scope in water supply', *Regional Science and Urban Economics* **18**(4), 479–502.

Kirkpatrick, C., Parker, D. and Zhang, Y.-F. (2006), 'An empirical analysis of state and private-sector provision of water services in africa', *The World Bank Economic Review.* **20**(1), 143–163.

Kirshen, P. H., Larsen, A. L., Vogel, R. M. and Moomaw, W. (2004), 'Lack of influence of climate on present cost of water supply in the USA', *Water Policy* **6**(4), 269–279.

Knapp, M. R. J. (1978), 'Economies of scale in sewage purification and disposal', *Journal of Industrial Economics* **27**(2), 163–183.

Komives, K., Wodon, Q., Foster, V., Abdullah, R. and Halpern, J. (2006), The distributional incidence of residential water and electricity subsidies, Policy Research Working Paper WPS 3878, The World Bank, Washington, D. C., USA.

Kostas, B. and Chrysostomos, S. (2006), 'Estimating urban residential water demand determinants and forecasting water demand for athens metropolitan area, 2000-2010', *South-Eastern Europe Journal of Economics* **4**(1), 47–59.

Krause, K., Chermak, J. M. and Brookshire, D. S. (2003), 'The demand for water: Consumer response to scarcity', *Journal of Regulatory Economics* **23**(2), 167–191.

Kundzewicz, Z. W., Mata, L. J., Arnell, N. W., Döll, P., Kabat, P., Jiménez, B., Miller, K., Oki, T., Sen, Z. and Shiklomanov, I. A. (2007), Freshwater resources and their management., *in* M. L. Parry, O. F. Canziani, J. P. Palutikof, P. J. V. der Linden and C. E. Hanson, eds, 'Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change', Cambridge University Press, Cambridge, UK, chapter 3, pp. 173–210.

Laffont, J.-J. and Tirole, J. (1993), *A Theory of Incentives in Procurement and Regulation*, The MIT Press, Cambridge, Massachusetts, USA; London, UK.

Largo, F. M., Inocencio, A. B. and David, C. C. (1998), Understanding household water demand for metro cebu, Discussion Paper Series 98-41, Philippine Institute for Development Studies, Makati City, Philippines.

Larson, B., Minten, B. and Razafindralambo, R. (2006), 'Unravelling the linkages between the millennium development goals for poverty, education, access to water and household water use in developing countries: Evidence from madagascar', *Journal of Development Studies* **42**(1), 22–40.

Larson, B. O. and Jr., H. E. H. (1951), 'Residential water use and family income', *Journal of the American Water Works Association* **43**(7), 605–611.

Lin, C. (2005), 'Service quality and prospects for benchmarking: Evidence from the peru water sector', *Utilities Policy* **13**(3), 230–239.

LNEC-ISA (2001), Programa nacional para o uso eficiente de água [national program for the efficient use of water], Technical report, INAG - Instituto da Água, Ministério do Ambiente e do Ordenamento do Território, Lisboa, Portugal. Created by LNEC - National Laboratory of Civil Engineering with the support of ISA - Higher Institute of Agronomy (Technical University of Lisbon).

Loehman, E. T. (2004), 'Cost recovery, efficiency, and economic organization for water utilities', *The B.E. Journal of Economic Analysis and Policy* **3**(1). Article 16. Available at: http://www.bepress.com/bejeap/contributions/vol3/iss1/art16.

Loehman, E. T. (2008), 'Pricing for water conservation with cost recovery', *Water Resources Research* **44**(8), W08450.

Lopes, S. H. (2008), 'Um preço nacional para os serviços de água?', *Água e Ambiente* **119**, 28–29.

Luis-Manso, P. A. (2007), Reform and Risk Management in the Urban Water Sector: The Role of Regulation, Phd thesis, École Polythechnique Féderale de Lausanne. Collège du management de la technologie CDM, Programme Management de la technologie et entrepreneuriat - Doctorat, Institut de logistique, économie et management de technologie ILEMT (Chaire de management des industries de réseau - La Poste MIR), Lausanne, Switzerland. EPFL thesis nr. 3966. PhD supervisor: Matthias Finger.

Lyman, R. A. (1992), 'Peak and off-peak residential water demand', *Water Resources Research* **28**(9), 2159–2167.

Lynk, E. L. (1993), 'Privatisation, joint production and the comparative efficiencies of private and public ownership: The UK water industry case', *Fiscal Studies* **14**(2), 98–116.

MA (1998), Decree-law 362/98 of november 18, Technical report, Ministério do Ambiente [Ministry of Environment], Lisboa, Portugal. Approves the Statutes of the Regulating Authority of Water and Water (IRAR - Instituto Regulador de Águas e Resíduos).

MacKinnon, J. G., White, H. and Davidson, R. (1983), 'Tests for model specification in the presence of alternative hypothesis: Some further results', *Journal of Econometrics* **21**(1), 53–70.

Male, J. W., Moriarty, J. B., Stevens, T. H. and Willis, C. E. (1991), 'Water supply costs for small private utilities', *Water Resources Bulletin* **27**(3), 521–526.

Malla, P. B. and Gopalakrishnan, C. (1997), 'Residential water demand in a fast-growing metropolis: The case of honolulu, hawaii', *International Journal of Water Resources Development* **13**(1), 35–52.

Manning, R. and Gallagher, D. (1982), 'Optimal water pricing and storage: The effect of discounting', *Water Resources Research* **18**(1), 65–70.

Mansur, E. T. and Olmstead, S. M. (2007), The value of scarce water: Measuring the inefficiency of municipal regulations, Working Paper 13513, NBER - National Bureau of Economic Research, Cambridge, Massachusetts, USA.

MAOT (2002), Decree-law 151/2002 of may 23, Technical report, Ministério do Ambiente e do Ordenamento do Território [Ministry of Environment and Spatial Planning], Lisboa, Portugal. Changes the Statutes of the Regulating Authority of Water and Water (IRAR - Instituto Regulador de Águas e Resíduos).

MAOTDR (2006), Decree-law 207/2006 of october 27, Technical report, Ministério do Ambiente, do Ordenamento do Território e do Desenvolvimento Regional [Ministry of Environment, Spatial Planning and Regional Development], Lisboa, Portugal. Approves the Organic Law of the Ministry of Environment, Spatial Planning and Regional Development.

MAOTDR (2007*a*), *PEAASAR II - Plano Estratégico de Abastecimento de Água e de Saneamento de Águas Residuais 2007-2013*, Ministério do Ambiente, do Ordenamento do Território e do Desenvolvimento Regional [Ministry of Environment, Spatial Planning and Regional Development].

MAOTDR (2007*b*), *Water Scarcity and Drought: A Priority of the Portuguese Presidency*, Ministério do Ambiente, do Ordenamento do Território e do Desenvolvimento Regional [Ministry of Environment, Spatial Planning and Regional Development].

MAOTDR (2008*a*), 'Decree-law n. 97/2008 of june 11 (economic and financial regime for water resources)', Diário da República, 1. série, n. 111, 2008-06-11. Ministério do

Ambiente, do Ordenamento do Território e do Desenvolvimento Regional [Ministry of Environment, Spatial Planning and Regional Development].

MAOTDR (2008*b*), 'Tariff regime for water supply, sewerage and waste services. decree-law proposal registered by the presidency of the council of ministers with the number DL 274/2008'. Ministério do Ambiente, do Ordenamento do Território e do Desenvolvimento Regional [Ministry of Environment, Spatial Planning and Regional Development]. Available at www.anmp.pt/anmp/doc/Dpeas/2008/div/rtspaasargrsu08011.pdf. Accessed on November 2008.

MAOTDR (2009), Decree-law 277/2009 of october 02, Technical report, Ministério do Ambiente, do Ordenamento do Território e do Desenvolvimento Regional [Ministry of Environment, Spatial Planning and Regional Development], Lisboa, Portugal. Approves the Organic of ERSAR - Entidade Reguladora dos Serviços de Água e Resíduos [Regulating Authority on Water and Waste Services].

Martin, R. C. and Wilder, R. P. (1992), 'Residential demand for water and the pricing of municipal water services', *Public Finance Quarterly* **20**(1), 93–102.

Martin, W. E., Ingram, H. M., Lancy, N. K. and Griffin, A. H. (1984), *Saving Water in a Desert City*, Resources for the Future, Johns Hopkins University Press, Baltimore, Maryland, USA.

Martin, W. E. and Kulakowski, S. (1991), 'Water price as a policy variable in managing urban water use: Tucson, arizona', *Water Resources Research* **27**(2), 157–166.

Martin, W. E. and Thomas, J. F. (1986), 'Policy relevance in studies of residential water demand', *Water Resources Research* **22**(13), 1735–1741.

Martínez-Espiñeira, R. (2002), 'Residential water demand in the northwest of spain', *Environmental and Resource Economics* **21**(2), 161–187.

Martínez-Espiñeira, R. (2003), 'Estimating water demand under increasing-block tariffs using aggregate data and proportions of users per block', *Environmental and Resource Economics* **26**(1), 5–23.

Martínez-Espiñeira, R. (2007), 'An estimation of residential water demand using co-integration and error correction techniques', *Journal of Applied Economics* **10**(1), 161–184.

Martínez-Espiñeira, R., García-Valiñas, M. A. and González-Gómez, F. (2009), 'Does private management of water supply services really increase prices? an empirical analysis', *Urban Studies* **46**(4), 923–945.

Martínez-Espiñeira, R. and Nauges, C. (2004), 'Is all domestic water consumption sensitive to price control?', *Applied Economics* **36**(15), 1697–1703.

Martins, M. R. V. (2007), Regulação Económica No Sector Das Águas: Promoção Da Concorrência e Sustentabilidade Tarifária, PhD thesis, Universidade de Coimbra, Faculdade de Economia, Coimbra, Portugal.

Martins, R., Coelho, F. and Fortunato, A. (2006), Evaluating cost structure of portuguese water utilities: Economies of scale and water losses, *in* 'RESER 2006 - XVIth International Conference of RESER - Services Governance and Public Policies', RESER - The European Research Network on Services and Space, Lisboa, Portugal, pp. 729–748.

Martins, R., Coelho, F. and Fortunato, A. (2008), Water losses and hydrographical regions influence on the cost structure of the portuguese water industry, Estudos do GEMF 06/2008, Grupo de Estudos Monetários e Financeiros, Faculdade de Economia da Universidade de Coimbra, Coimbra, Portugal.

Martins, R. and Fortunato, A. (2004), A procura residencial de água em portugal, Working paper presented at the 7th APRH water congress held in lisboa, LNEC - laboratório nacional de engenharia civil, in march 8-12, 2004, APRH - Associação Portuguesa de Recursos Hídricos [Portuguese Water Resources Association], Lisboa, Portugal.

Martins, R. and Fortunato, A. (2005*a*), 'A procura residencial de água em portugal: Preços como instrumento de gestão de procura?', *Tecnologia da Água* **6**, 14–28.

Martins, R. and Fortunato, A. (2005*b*), Residential water demand under block rates - a portuguese case study, Estudos do GEMF 9/2005, Grupo de Estudos Monetários e Financeiros - Faculdade de Economia - Universidade de Coimbra.

Martins, R. and Fortunato, A. (2007), 'Residential water demand under block rates - a portuguese case study', *Water Policy* **9**(2), 217–230.

Martins, R., Fortunato, A. and Coelho, F. (2006), Cost structure of the portuguese water industry: A cubic cost function application, Estudos do GEMF 9/2006, Grupo de Estudos Monetários e Financeiros, Faculdade de Economia da Universidade de Coimbra, Coimbra, Portugal.

Mas-Collel, A., Winston, M. D. and Green, J. R. (1995), *Microeconomic Theory*, Oxford University Press, New York, USA.

Mazzanti, M. and Montini, A. (2006), 'The determinants of residential water demand: Empirical evidence for a panel of italian municipalities', *Applied Economics Letters* **13**(2), 107–111.

Mendes, A., Avillez, J., Mendes, P., Gomes, F., Martins, S., Cardoso, P., Cardoso, S., Costa, D., Mendes, S., Robalo, G. and Silva, S. (2006), 'Inventário nacional de sistemas de abastecimento de água e de águas residuais', *Tecnologia da Água* **1**, 34–42.

Meroz, A. (1968), A quantitative analysis of urban water demand in developing coutries, Working Paper 17, International Bank for Reconstruction and Development, Economics Department, Washington, D. C., USA.

Merrifield, J. and Collinge, R. (1999), 'Efficient water pricing policies as an appropriate municipal revenue source', *Public Works Management and Policy* **4**(2), 119–130.

Metcalf, L. (1926), 'Effects of water rates and growth in population upon per capita consumption', *Journal of the American Water Works Association* **15**(1), 1–22.

Miaou, S.-P. (1990), 'A stepwise time series regression procedure for water demand model identification', *Water Resources Research* **26**(9), 1887–1897.

Miyawaki, K., Omori, Y. and Hibiki, A. (2008), Bayesian estimation of demand functions under block rate pricing, Discussion Paper CIRJE-F-568, CIRJE - Center for International Research on the Japanese Economy, Tokyo, Japan.

Mizon, G. E. and Richard, J. F. (1986), 'The encompassing principle and its application to testing non-nested hypothesis', *Econometrica* **54**(3), 654–678.

Mizutani, F. and Urakami, T. (2001), 'Identifying network density and scale economies for japanese water supply organizations', *Papers in Regional Science* **80**(2), 212–230.

Moncur, J. E. T. (1987), 'Urban water pricing and drought management', *Water Resources Research* **23**(3), 393–398.

Moncur, J. E. T. (1989), 'Drought episodes management: The role of price', *Water Resources Bulletin* **25**(3), 499–505.

Moncur, J. E. T. and Pollock, R. L. (1988), 'Scarcity rents for water: A valuation and pricing model', *Land Economics* **64**(1), 62–72.

Monteiro, H. (2005), Water pricing models: A survey, Working Paper 2005/45, DINÂMIA, Research Centre on Socioeconomic Change, Lisboa, Portugal.

Monteiro, H. (2007), Recuperação de custos no sector de abastecimento de água e de drenagem e tratamento de águas residuais em portugal, Working Paper 2007/57, DINÂMIA - Research Centre on Socioeconomic Change, Lisboa, Portugal.

Monteiro, H. (2008), Evolution of cost recovery levels in the portuguese water supply and wastewater industry 1998-2005, Working Paper 2008/73, DINÂMIA, Research Centre on Socioeconomic Change, Lisboa, Portugal.

Monteiro, H. and Roseta-Palma, C. (2007), Caracterização dos tarifários de abastecimento de água e saneamento em portugal, Working Paper 2007/58, DINÂMIA - Research Centre on Socioeconomic Change, Lisboa, Portugal.

Montginoul, M. (2007), 'Analysing the diversity of water pricing structures: The case of france', *Water Resources Management* **21**(5), 861–871.

Morgan, W. D. (1973), 'Residential water demand. the case from micro data', *Water Resources Research* **9**(4), 1065–1067.

Morgan, W. D. (1974), 'A time series demand for water using micro data and binary variables', *Water Resources Bulletin* **10**(4), 697–702.

Morgan, W. D. and Smolen, J. C. (1976), 'Climatic indicators in the estimation of municipal water demand', *Water Resources Bulletin* **12**(3), 511–518.

Mu, X., Whittington, D. and Briscoe, J. (1990), 'Modeling village water demand behavior: A discrete choice approach', **26**(4), 521–529.

Musolesi, A. and Nosvelli, M. (2007), 'Dynamics of residential water consumption in a panel of italian municipalities', *Applied Economics Letters* **14**(6), 441–444.

Mylopoulos, Y. A., Mentes, A. K. and Theodossio, I. (2004), 'Modeling residential water demand using household data: A cubic approach', *Water International* **29**(1), 105–113.

Nataraj, S. and Hanemann, W. M. (2008), Does marginal price matter? a regression discontinuity approach to estimating water demand, CUDARE Working Paper 1077, Department of Agricultural and Resource Economics, University of California at Berkeley, Berkeley, California, USA.

Nauges, C. and Berg, C. V. D. (2008*a*), 'Economies of density, scale and scope in the water supply and sewerage sector: A study of four developing and transition economies', *Journal of Regulatory Economics* **34**(2), 144–163.

Nauges, C. and Berg, C. V. D. (2008*b*), Spatial heterogeneity in the cost structure of water and sanitation services: A cross-country comparison of conditions for scale economies, Technical report. Available at http://www2.toulouse.inra.fr/lerna/chercheurs/nauges/fichiers/WP3.pdf.

Nauges, C. and Berg, C. V. D. (2009), 'Demand for piped and non-piped water supply services: Evidence from southwest sri lanka', *Environmental and Resource Economics* **44**(5), 535–549.

Nauges, C. and Blundell, R. (2002), Estimating residential water demand under block rate pricing: A nonparametric approach, Working Paper 02.21.096, LERNA-INRA - Laboratoire d'Economie des Resources Naturelles, Institut National de la Recherche Agronomique, Toulouse, France.

Nauges, C. and Reynaud, A. (2001), 'Estimation de la demande domestique d'eau potable en france', *Revue Economique* **52**(1), 167–185.

Nauges, C. and Strand, J. (2007), 'Estimation of non-tap water demand in central american cities', *Resource and Energy Economics* **29**(3), 165–182.

Nauges, C. and Thomas, A. (2000), 'Privately-operated water utilities, municipal price negotiation, and estimation of residential water demand: The case of france', *Land Economics* **76**(1), 68–85.

Nauges, C. and Thomas, A. (2003), 'Long-run study of residential water consumption', *Environmental and Resource Economics* **26**(1), 25–43.

Nauges, C. and Whittington, D. (2008), Estimation of water demand in developing countries: An overview, Working Paper 08.20.264, LERNA-INRA - Laboratoire d'Economie des Resources Naturelles, Institut National de la Recherche Agronomique, Toulouse, France.

Nieswiadomy, M. L. (1992), 'Estimating urban residential water demand: Effects of price structure, conservation, and education', *Water Resources Research* **28**(3), 609–615.

Nieswiadomy, M. L. and Cobb, S. L. (1993), 'Impact of pricing structure selectivity on urban water demand', *Contemporary Policy Issues* **11**(6), 101–113.

Nieswiadomy, M. L. and Molina, D. J. (1988), 'Urban water demand estimates under increasing block rates', *Growth and Change* **19**(1), 1–12.

Nieswiadomy, M. L. and Molina, D. J. (1989), 'Comparing residential water demand estimates under decreasing and increasing block rates using household data', *Land Economics* **65**(3), 280–289.

Nieswiadomy, M. L. and Molina, D. J. (1991), 'A note on price perception in water demand models', *Land Economics* **67**(3), 352–359.

Nordin, J. A. (1976), 'A proposed modification of taylor's demand analysis: Comment', *The Bell Journal of Economics* **7**(2), 719–721.

OECD (1999*a*), *Household Water Pricing in OECD Countries*, OECD - Organisation for Economic Co-operation and Development, Environment Directorate, Environment Policy Committee, Paris, France.

OECD (1999*b*), *Industrial Water Pricing in OECD Countries*, OECD - Organisation for Economic Co-operation and Development, Environment Directorate, Environment Policy Committee, Paris, France.

OECD (1999*c*), *The Price of Water - Trends in OECD Countries*, OECD - Organisation for Economic Co-operation and Development, Paris, France.

OECD (2003*a*), *Social Issues in the Provision and Pricing of Water Services*, OECD - Organisation for Economic Co-operation and Development, Paris, France.

OECD (2003*b*), *Water - Performance and Challenges in OECD Countries*, Environmental Performance Reviews, OECD - Organisation for Economic Co-operation and Development, Paris, France.

OECD (2006), *Water: The Experience in OECD Countries*, Environmental Performance Reviews, OECD - Organisation for Economic Cooperation and Development, Paris, France.

OECD (2009), *Managing Water for All: An OECD Perspective on Pricing and Financing*, OECD Publishing, Paris, France.

Olmstead, S. M. (2009), 'Reduced-form vs. structural models of water demand under non-linear prices', *Journal of Business and Economic Statistics* **87**(1), 84–94.

Olmstead, S. M., Hanemann, W. M. and Stavins, R. N. (2007), 'Water demand under alternative price structures', *Journal of Environmental Economics and Management* **54**(2), 181–198.

Palencia, L. C. (1988), 'Residential water demand in metro manila', *Water Resources Bulletin* **24**(2), 275–279.

Panzar, J. C. and Willig, R. D. (1977), 'Economies of scale in multi-output production', *Quarterly Journal of Economics* **91**(3), 481–494.

Pashardes, P. and Hajispyrou, S. (2002), Consumer demand and welfare under increasing block pricing, Discussion Paper 2002-7, Department of Economics, University of Cyprus, Nicosia, Cyprus.

Piacenza, M. and Vannoni, D. (2004), 'Choosing among alternative cost function specifications: An application to italian multi-utilities', *Economics Letters* **82**(3), 415–422.

Pint, E. M. (1999), 'Household responses to increased water rates during the california drought', *Land Economics* **75**(2), 246–266.

Piper, S. (2003), 'Impact of water quality on municipal water price and residential water demand and implications for water supply benefits', *Water Resources Research* **39**(5), WES1.1–WES1.9.

Pires, J. S. (2007*a*), 'Consumer tariffs in practice -the portuguese experience'. OECD expert meeting on "sustainable financing for affordable water services: from theory to practice" held in Paris, France, 14 November 2007.

Pires, J. S. (2007*b*), 'A regulação dos serviços de águas e resíduos em portugal'. IRAR-CEDIPRE Conference, held at the Lisbon Technopole, 21-22 November 2007, Lisboa, Portugal. [Instituto Regulador de Águas e Rsíduos / Centro de Estudos de Direito Público e Regulação].

Point, P. (1993), 'Partage de la resource en eau et demande d'Alimentacion en eau potable', *Revue Economique* **44**(4), 849–862.

Price, J. (1993), Comparing the cost of water delivered: Initial research into the impact of operating conditions on company costs, Research Paper 1, OFWAT - Water Services Regulation Authority, Birmingham, UK.

Raffiee, K., Narayanan, R., Harris, T., Lambert, D. and Collins, J. (1993), 'Cost analysis of water utilities: A goodness-of-fit approach', *Atlantic Economic Journal* **21**(3), 18–29.

Renwick, M. E. and Archibald, S. O. (1998), 'Demand side management policies for residential water use: Who bears the conservation burden?', *Land Economics* **74**(3), 343–359.

Renwick, M. E. and Green, R. D. (2000), 'Do residential water demand side management policies measure up? an analysis of eight california water agencies', *Journal of Environmental Economics and Management* **40**(1), 37–55.

Renzetti, S. (1992), 'Evaluating the welfare effects of reforming municipal water prices', *Journal of Environmental Economics and Management* **22**(2), 147–163.

Renzetti, S. (1999), 'Municipal water supply and sewage treatment: Costs, prices and distortions', *Canadian Journal of Economics* **32**(3), 688–704.

Renzetti, S. (2002), *The Economics of Water Demands*, Kluwer Academic Publishers, Boston, USA.

Renzetti, S. (2006), Are the prices right? balancing efficiency, equity, and sustainability in water pricing, *in* K. Bakker, ed., 'Eau Canada: The Future of Canada's Water', University of Washington Press (distributed for UBC Press), Vancouver, Canada.

Renzetti, S. and Dupont, D. (2004), 'The performance of municipal water utilities: Evidence on the role of ownership', *Journal of Toxicology and Environmental Health Part A* **67**(20-22), 1861–1878.

Renzetti, S. and Dupont, D. (2008), Measuring the technical efficiency of municipal water suppliers: The role of environmental factors, Working Paper 0802, Brock University, Department of Economics, St. Catherines, Ontario, Canada.

Reynaud, A. (2008), Doing better with less: Implementing peak-load pricing for managing residential water demand, Technical report. Paper presented at the 16th Annual Conference of EAERE - European Association of Environmental and Resource Economists (EAERE 2008), held in Gothenburg, Sweden 25-28 June 2008.

Reynaud, A., Renzetti, S. and Villeneuve, M. (2005), 'Residential water demand with endogenous pricing: The canadian case', *Water Resources Research* **41**(11), W11409.1–W11409.11.

Reynaud, A. and Thomas, A. (2005), 'Demande domestique en eau et choix de délégation: Le cas français', *Revue Economique* **56**(5), 1145–1168.

Ribeiro, A. K. B. (2007), A Recuperação Dos Custos e a Lei Da Água, Master's thesis, Department of Civil Engineering - School of Science and Technology - University of Coimbra, Coimbra, Portugal. Dissertação para a obtenção do grau de mestre em Engenharia Civil.

Ribeiro, A. K., Serra, P. C. and Cunha, M. D. C. (2006), Os antecedentes do princípio da recuperação de custos na DQA, Technical report. Paper presented at the 5th Iberian Conference on Water Planning and Management held in Faro, Portugal, in December 2006.

Rietveld, P., Rouwendal, J. and Zwart, B. (2000), 'Block rate pricing of water in indonesia: An analysis of welfare effects', *Bulletin of Indonesian Economic Studies* **36**(3), 73–92.

Riley, J. G. and Scherer, C. R. (1979), 'Optimal water pricing and storage with cyclical supply and demand', *Water Resources Research* **15**(2), 233–239.

Riordan, C. (1971*a*), 'General multistage marginal cost dynamic programming model for the optimization of a class of investment-pricing decisions', *Water Resources Research* **7**(2), 245–253.

Riordan, C. (1971*b*), 'Multistage marginal cost model of investment pricing decisions: Application to urban water supply treatment facilities', *Water Resources Research* **7**(3), 463–478.

Rizaiza, O. S. A. (1991), 'Residential water usage: A case study of the major cities of the western region of saudi arabia', *Water Resources Research* **27**(5), 667–671.

Roseta-Palma, C. (2002), Análise económica da água em portugal: Os desafios da directiva quadro, Technical report. Paper presented at the 3rd Iberian Congress on Water Planning and Management held in Seville, Spain, November 2002.

Roseta-Palma, C. and Monteiro, H. (2008), Pricing for scarcity, Working Paper 2008/65, DINÂMIA, Research Centre on Socioeconomic Change, Lisboa, Portugal.

Roseta-Palma, C., Monteiro, H., Meireles, M., Mestre, F. and Sugahara, G. (2006), Strategic evaluation of environment and risk prevention - national evaluation report - portugal, Technical report, GHK for the European Commission.

Rouse, M. J. (2007), *Institutional Governance and Regulation of Water Services: The Essential Elements*, IWA Publishing, London, UK.

Ruijs, A. (2009), 'Welfare and distribution effects of water pricing policies', *Environmental and Resource Economics* **43**(12), 161–182.

Ruijs, A., Zimmermann, A. and Berg, M. V. D. (2008), 'Demand and distributional effects of water pricing policies', *Ecological Economics* **66**(2-3), 506–516.

Saal, D. and Reid, S. (2004), Estimating opex productivity growth in english and welsh water and sewerage companies: 1993-2003, Research Paper 0434, Aston Business School, Birmingham, UK.

Saal, D. S. and Parker, D. (2000), 'The impact of privatization and regulation on the water and sewerage industry in england and wales: A translog cost function model', *Managerial and Decision Economics* **21**(6), 253–268.

Sabbioni, G. (2008), 'Efficiency in the brazilian sanitation sector', *Utilities Policy* **16**(1), 11–20.

Saleth, M. R. and Dinar, A. (1997), Satisfying urban thirst: Water supply augmentation and pricing policy in hyderabad city, india, Technical Paper 395, The World Bank, Washington, D. C., USA.

Sampaio, A. (2008), Fronteiras estocásticas e avaliação da eficiência: Serviço público de distribuição de água, Technical report. Comunicação ao 5o Congresso Luso-Moçambicano de Engenharia realizado em Maputo, 2-4 Setembro 2008.

Santos, F. D., Forbes, K. and Moita, R., eds (2002), *Climate Change in Portugal. Scenarios, Impacts and Adaptation Measures - SIAM Project*, Gradiva, Lisboa, Portugal.

Santos, F. D. and Miranda, P., eds (2006), *Alterações Climáticas Em Portugal. Cenários, Impactos e Medidas de Adaptação - Projecto SIAM II*, Gradiva, Lisboa, Portugal.

Santos, R. F. (2006), 'As políticas tarifárias no sector da água [tariff policies in the water industry]'. Sessão Técnica A Economia da Água [Technical session: Water Economics], organized by the APRH - Portuguese Association of Water Resources at the National Water Institute (INAG) on October 10, 2006.

Sauer, J. (2005), 'Economies of scale and firm size optimum in rural water supply', *Water Resources Research* **41**(11), 1–13.

Schaffer, M. E. (2007), 'Xtivreg2: Stata module to perform extended IV/2SLS, GMM and AC/HAC, LIML and k-class regression for panel data models', http://ideas.repec.org/c/boc/bocode/s456501.html.

Schefter, J. E. (1987), 'Increasing block rate tariffs as faulty transmitters of marginal willingness to pay', *Land Economics* **63**(1), 272–280.

Schefter, J. E. and David, E. L. (1985), 'Estimating residential water demand under multi-part tariffs using aggregate data', *Land Economics* **61**(3), 272–279.

Schleich, J. (2009), How low can you go? price responsiveness of german residential water demand, Technical report. Paper presented at the 17th Annual Conference of EAERE - European Association of Environmental and Resource Economists, Amsterdam, 24-27 June.

Schleich, J. and Hillenbrand, T. (2009), 'Determinants of residential water demand in germany', *Ecological Economics* **68**(6), 1756–1769.

Schneider, M. L. and Whitlatch, E. E. (1991), 'User-specific water demand elasticities', *Journal of Water Resources Planning and Management* **117**(1), 52–73.

Schoengold, K. and Zilberman, D. (2009), The economics of tiered pricing and cost functions: Are equity, cost recovery, and economic efficiency compatible goals?, Technical report. Paper presented at the 17th Annual Conference of EAERE - European Association of Environmental and Resource Economists, Amsterdam, 24-27 June.

Schröter, D., Cramer, W., Leemans, R., Prentice, C. I., Araújo, M. B., Arnell, N. W., Bondeau, A., Bugmann, H., Carter, T. R., Gracia, C. A., de la Vega-Leinert, A. C., Erhard, M., Ewert, F., Glendining, M., House, J. I., Kankaanpää, S., Klein, R. J. T., Lavorel, S., Lindner, M., Metzger, M. J., Meyer, J., Mitchell, T. D., Reginster, I., Rounsevell, M., Sabaté, S., Sitch, S., Smith, B., Smith, J., Smith, P., Sykes, M. T., Thonicke, K., Thuiller, W., Tuck, G., Zaehle, S. and Zierl, B. (2005), 'Ecosystem service supply and vulnerability to global change in europe', *Science* **310**(5752), 1333–1337.

Schuck, E. C. and Green, G. P. (2002), 'Supply-based water pricing in a conjunctive use system: Implications for resource and energy use', *Resource and Energy Economics* **24**(3), 175–192.

Seidel, H. F. and Baumann, E. R. (1957), 'A statistical analysis of water works data for 1955', *Journal of the American Water Works Association* **42**(12), 1531–1566.

Serra, P. (2009), 'Balanço PEAASAR II'. Presentation to the conference "Balanço do Plano Estratégico de Abastecimento e Saneamento de Águas Residuais (2007-2013)

- PEAASAR II", held by APRH, APDA and APESB in Lisbon, Portugal (17 June 2009). Available at http://www.aprh.pt/pdf/pedro-serra.pdf.

Serra, P. C. (2001), Water pricing policies in portugal, *in* EC, ed., 'Pricing Water: Economics, Environment and Society - Conference Proceedings, Sintra, 6 and 7 September 1999', European Commission, pp. 283–288.

Shaw, W. D. (2005), *Water Resource Economics and Policy*, Edward Elgar Publishing, Cheltenham, UK.

Shen, Y., Oki, T., Utsumi, N., Kanae, S. and Hanasaki, N. (2008), 'Projection of future world water resources under SRES scenarios: Water withdrawal', *Hydrological Sciences Journal* **53**(1), 11–33.

Shih, J.-S., Harrington, W., Pizer, W., and Gillingham, K. (2006), 'Economies of scale in community water systems', *Journal of the American Water Works Association* **98**(9), 100–108.

Shin, J.-S. (1985), 'Perception of price when information is costly: Evidence from residential electricity demand', *Review of Economics and Statistics* **67**(4), 591–598.

Sibly, H. (2006), 'Urban water pricing', *Agenda* **13**(1), 17–30.

Smakhtin, V., Revenga, C. and Döll, P. (2004), 'A pilot global assessment of environmental water requirements and scarcity', *Water International* **29**(3), 307–317.

Souza, G. D. S., Faria, R. C. and Moreira, T. B. S. (2008), 'Efficiency of brazilian public and private water utilities', *Estudos Econômicos* **38**(4), 905–917.

Statzu, V. and Strazzera, E. (2008), Studio della domanda di servizi di pubblica utilità: UnŠanalisi panel dei consumi residenziali di acqua, Quaderni di Lavoro Crenos 08/03, Temi Economici della Sardegna, Cagliari, Sardegna, Italy.

Stevens, T. H., Miller, J. and Willis, C. E. (1992), 'Effect of price structure on residential water demand', *Water Resources Bulletin* **28**(4), 681–685.

Stone and Consultants, W. (2004.), Investigation into evidence for economies of scale in the water and sewerage industry in england and wales - final report, Technical report, "Stone and Webster Consultants", London, UK.

Strand, J. and Walker, I. (2005), ‘Water markets and demand in central american cities’, *Environment and Development Economics* **10**(3), 313–335.

Strong, A. and Smith, V. K. (2008), Reconsidering the economics of demand analysis with kinked budget constraints, Working Paper 14304, NBER - National Bureau of Economic Research, Cambridge, Massachusetts, USA.

Swallow, S. K. and Marin, C. (1988), ‘Long-run price inflexibility and efficiency loss for municipal water supply’, *Journal of Environmental Economics and Management* **15**(2), 233–247.

Taylor, L. D. (1975), ‘The demand for electricity: A survey’, *Bell Journal of Economics* **6**(1), 74–110.

Taylor, R. G., McKean, J. R. and Young, R. A. (2004), ‘Alternate price specifications for estimating residential water demand with fixed fees’, *Land Economics* **80**(3), 463–475.

Teeples, R. and Glyer, D. (1987*a*), ‘Production functions for water delivery systems: Analysis and estimation using dual cost function and implicit price specifications’, *Water Resources Research* **23**(5), 765–773.

Teeples, R. K. and Glyer, D. (1987*b*), ‘Cost of water delivery systems: Specification and ownership effects’, *Review of Economics and Statistics* **69**(3), 399–408.

Thomas, J. F. and Syme, G. J. (1988), ‘Estimating residential price elasticity of demand for water: A contingent valuation approach’, *Water Resources Research* **24**(11), 1847–1857.

Torres, M. and Paul, C. J. M. (2006), ‘Driving forces for consolidation or fragmentation of the US water utility industry: A cost function approach with endogenous output’, *Journal of Urban Economics* **59**(1), 104–120.

Tsegai, D. W., Linz, T. and Kloos, J. (2009), Economic analysis of water supply cost structure in the middle olifants sub-basin of south africa, Discussion Papers on Development Policy 129, University of Bonn - Center for Development Research (ZEF), Bonn, Germany.

Turnovsky, S. J. (1969), 'The demand for water: Some empirical evidence on consumers' response to a commodity uncertain in supply', *Water Resources Research* **5**(2), 350–361.

Um, M.-J., Kwak, S.-J. and Kim, T.-Y. (2002), 'Estimating willingness to pay for improved drinking water quality using averting behavior method with perception measure', *Environmental and Resource Economics* **21**(3), 287–302.

UN-Water (2007), Coping with water scarcity - challenge of the twenty-first century, Technical report, United Nations.

UNDP (2006), *Human Development Report 2006 - Beyond Scarcity: Power, Poverty and the Global Water Crisis*, United Nations Development Programme, New York, USA.

UNDP (2007), *Human Development Report 2007/2008 - Fighting Climate Change: Human Solidarity in a Divided World*, United Nations Development Programme, New York, USA.

UNEP (2007), *GEO 4 - Global Environment Outlook - Environment for Development*, United Nations Environment Programme, Nairobi, Kenya.

UNEP (2008), *Vital Water Graphics: An Overview of the State of the World's Fresh and Marine Waters - 2nd Edition - 2008*, United Nations Environment Programme, Nairobi, Kenya. Available at http://www.unep.org/dewa/vitalwater/index.html.

Unnerstall, H. (2007), 'The principle of full cost recovery in the EU-water framework directive - genesis and content', *Journal of Environmental Law* **19**(1), 29–42.

Urakami, T. (2004), The effects of subsidies on the cost structure of japanese water supply organizations, Technical report. Paper presented at the 44th Conference of the European Regional Science Association - ERSA 2004 conference held in Porto, Portugal in 25-29 August, 2004.

Urakami, T. (2005), Identifying scale economies for different types of water supply organizations in japan, Technical report. Paper presented at the 45th Conference of the European Regional Science Association - ERSA 2005 conference held in Amsterdam, Netherlands, in 23-27 August 2005.

Urakami, T. (2007), 'Economies of vertical integration in the japanese water supply industry', *Jahrbuch für Regionalwissenschaft* **27**(2), 129–141.

Urakami, T. and Parker, D. (2009), The effects of consolidation amongst japanese water utilities: A hedonic cost function analysis, Technical report. Paper presented at the 36th annual conference of EARIE - European Association of Industrial Economics, 3-5 September 2009, Ljubljana, Slovenia.

Urakami, T. and Tanaka, T. (2009), Economies of scale and scope in the japanese water industry, Technical report. Paper presented at the 4th International Symposium on Economic Theory, Policy and Applications 3-6 August 2009, Athens, Greece.

Varian, H. R. (1992), *Microeconomic Analysis*, 3rd edn, W. W. Norton Company, New York, USA and London, UK.

Verbeek, M. (2000), *A Guide to Modern Econometrics*, John Wiley and Sons, Chichester, West Sussex, UK.

Walter, M., Cullmann, A., Hirschhausen, C. V., Wand, R. and Zschille, M. (2009), 'Quo vadis efficiency analysis of water distribution? a comparative literature review', *Utilities Policy* **17**(3-4), 225–232.

Walters, L. L. and Young, R. A. (1994), Economic factors affecting residential water demand in colorado, Completion report 175, Colorado Water Resources Research Institute, Fort Collins, Colorado, USA.

Wang, H., Xie, J. and Li, H. (2008), Domestic water pricing with household surveys: A study of acceptability and willingness to pay in chongqing, china, Policy Research Working Paper 4690, The World Bank, Development Research Group, Sustainable Rural and Urban Development Team, Washington, D. C., USA.

WATECO (2003), Economia e ambiente, metodologia de aplicação da directiva quadro da água, documento de orientação, Technical report, Wateco Group, European Commission, Lisboa, Portugal.

Weber, J. A. (1989), 'Forecasting demand and measuring price elasticity', *Journal of the American Water Works Association* **81**(5), 57–65.

Whitehead, J. C. (1995), 'Willingness to pay for quality improvements: Comparative statics and interpretation of contingent valuation results', *Land Economics* **71**(2), 207–215.

Whittington, D. (1992), 'Possible adverse effects of increasing block water tariffs in developing countries', *Economic Development and Cultural Change* **41**(1), 75–87.

Williams, M. and Suh, B. (1986), 'The demand for water by customer class', *Applied Economics* **18**(12), 1275–1289.

Wilson, L. (1989), 'Addition of a climate variable to the howe and linaweaver western sprinkling equation', *Water Resources Research* **25**(6), 1067–1069.

Wilson, R. (1993), *Nonlinear Pricing*, Oxford University Press, New York, USA.

Wong, S. T. (1972), 'A model of municipal water demand: A case study of northeastern illinois', *Land Economics* **48**(1), 34–44.

Woo, C. K. (1992), 'Drought management, service interruption, and water pricing: Evidence from hong kong', *Water Resources Research* **28**(10), 2591–2595.

Wooldridge, J. M. (2001), *Econometric Analysis of Cross Section and Panel Data*, 1st edn, The MIT Press, Cambridge, Massachusetts, USA; London, UK.

Worthington, A. C. and Hoffman, M. (2008), 'An empirical survey of residential water demand modelling', *Journal of Economic Surveys* **22**(5), 842–871.

WWAP (2006), *Water: A Shared Responsibility. The 2nd United Nations World Water Development Report*, United Nations Educational, Scientific and Cultural Organization (UNESCO) and Berghahn Books, Paris, France; New York, USA. United Nations World Water Assessment Programme.

WWAP (2009), *Water in a Changing World. The 3rd United Nations World Water Development Report*, United Nations Educational, Scientific and Cultural Organization (UNESCO) and Earthscan, Paris, France; London, UK. United Nations World Water Assessment Programme.

Xayavong, V., Burton, M. and White, B. (2008), Estimating urban residential water demand with increasing block prices: The case of perth, western australia, Working Paper 0704, The University of Western Australia, School of Agricultural and Resource Economics, Crawley, Western Australia, Australia.

Yoo, S.-H. (2007), 'Estimation of household tap water demand function with correction for sample selection bias', *Applied Economics Letters* **14**(14), 1079–1082.

Young, C. E., Kinsley, K. R. and Sharpe, W. E. (1983), 'Impact on residential water consumption of an increasing rate structure', *Water Resources Bulletin* **19**(1), 81–88.

Young, R. A. (1973), 'Price elasticity of demand for municipal water: A case study of tucson, arizona', *Water Resources Research* **9**(4), 1068–1072.

Zarnikau, J. (1994), 'Spot market pricing of water resources and efficient means of rationing water resources during scarcity', *Resource and Energy Economics* **16**(3), 189–210.

Zellner, A. (1962), 'An efficient method of estimating seemingly unrelated regressions and tests for aggregation bias', *Journal of the American Statistical Association* **57**(298), 348–368.